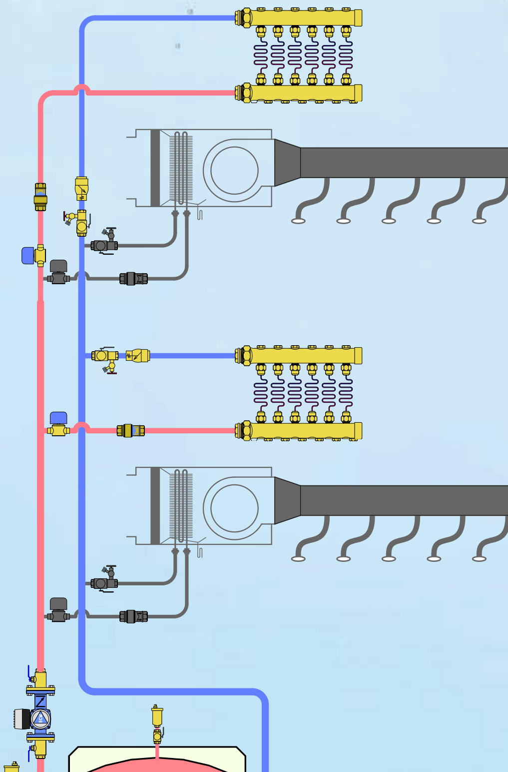
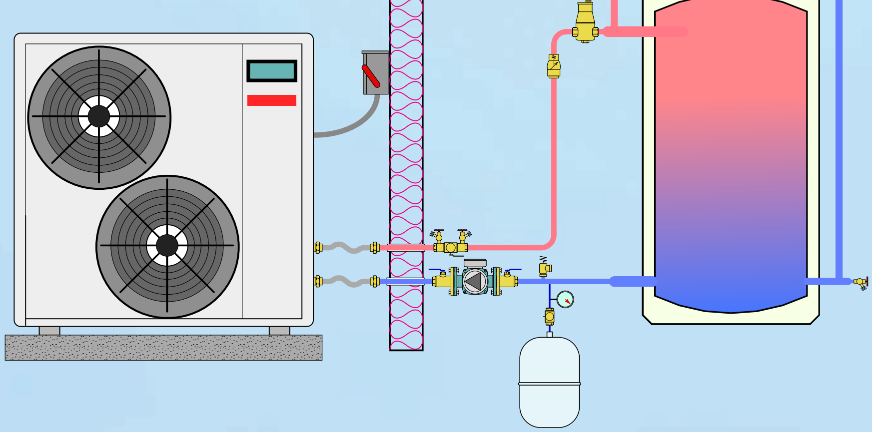
HP9-0118

SPACE PAK HYDRONICS

Solstice Heat Pump
Application Manual

a waterworks *publication*

SPACEPAK SOLSTICE HEAT PUMP APPLICATION MANUAL

INTRODUCTION

Heat pumps are a vitally important and rapidly growing sector of the global HVAC market. They are used in a wide variety of applications, including building heating and cooling, domestic water heating, pool heating, heat recovery, and several specialty systems. They are available in many different sizes and configurations, depending on the loads to which they are matched and the materials they absorb heat from and deliver heat to.

This publication deals with a specific type of heat pump called an "air-to-water" heat pump. When operating in heating mode, this heat pump absorbs heat from outside air and delivers it to hydronic distribution systems within a building. In cooling mode, the heat pump chills a fluid that circulates through a hydronic distribution system within the building and rejects the absorbed heat to outside air.

Modern air-source heat pumps can work in a wide variety of climates where outdoor temperatures can exceed 100ºF in summer, and drop below 0ºF in winter. Their operating range is much wider than the air-source heat pumps used during the 20th century.

Air-source heat pumps can also be used at just about any building site. They don't require wells, trenches or thousands of feet of buried piping, which are common with geothermal heat pump systems. All that's required for a heat source, or for heat rejection, is the air outside of a building.

A wide variety of systems can be created by combining the adaptability and extended operating range of modern air-source heat pumps with hydronics technology. This manual presents several such systems as "templates" that designers can use to build specific systems using SpacePak Solstice heat pumps.

These templates are not meant to be complete installation drawings for any specific system. Instead, *they are meant to demonstrate concepts that leverage the strengths of both the SpacePak Solstice heat pumps and modern hydronics technology*. Those familiar with basic hydronic system design can use these concepts as "starting points" from which a distinct and complete system design can be developed for a specific project.

This manual begins by discussing the operating characteristics of heat pumps. It continues by describing details that are essential for good system performance and long system life. It culminates with 10 templates that pull all the previously described details together.

Each template takes the form of a piping schematic, electrical wiring schematic, a detailed description of operation, and suggested controller settings. These are all essential in properly documenting a systems design to ensure proper installation, and a lasting record of exactly how the system is supposed to operate.

We hope you find this application manual to be a valuable resource in applying SpacePak Solstice heat pumps.

If you have questions or comments on the manual, please contact SpacePak technical assistance at 1-800-465-8558.

Sincerely,
The SpacePak team

1. OVERVIEW OF AIR-SOURCE HEAT PUMPS

A fundamental concept of thermodynamics is that heat "naturally" moves from materials at higher temperature to other materials at lower temperature. A common example is the movement of heat through the exterior surfaces of a building into cooler outside air.

It is also possible to move heat from materials at lower temperature to materials at higher temperature. However, this is not a process that occurs naturally. It requires the use of a heat pump.

Heat pumps can convert vast amounts of otherwise unusable low-temperature energy into heat at sufficient temperatures to warm buildings, heat domestic water or supply heat to other useful loads.

The low-temperature material from which the heat pump absorbs heat is called the *source*. The higher-temperature material into which the heat pump delivers heat is called the *sink*.

When used to heat buildings, heat pumps can gather low-temperature heat from sources such as outdoor air, ground water, lakes or ponds, or tubing buried in the ground. The temperature of this heat is increased within the heat pump, and it is then released into a building.

Heat pumps that extract low-temperature heat from lakes, ponds, wells or tubing buried in the ground use water, or a mixture of water and antifreeze, to convey heat from those sources to the heat pump. They are called "water-source" heat pumps.

Water-source heat pumps that deliver higher-temperature heat using a forced-air stream are more specifically called water-to-air heat pumps. Those that deliver heat using a hydronic distribution system are known as water-to-water heat pumps.

Heat pumps that extract low-temperature heat from outside air are called *air-source* heat pumps. They are common in North America. Most of the air-source heat pumps currently used in North America are configured to deliver higher-temperature heat to the building using a forced-air distribution system. This leads to the more specific classification as air-to-air heat pumps.

Past perceptions of air-source heat pumps:

The "classic" air-source heat pump for residential heating and cooling debuted in North America during the 1970s. These systems had two major subassemblies: an outdoor condenser unit, and an indoor air handler, which were connected by refrigeration piping and wiring.

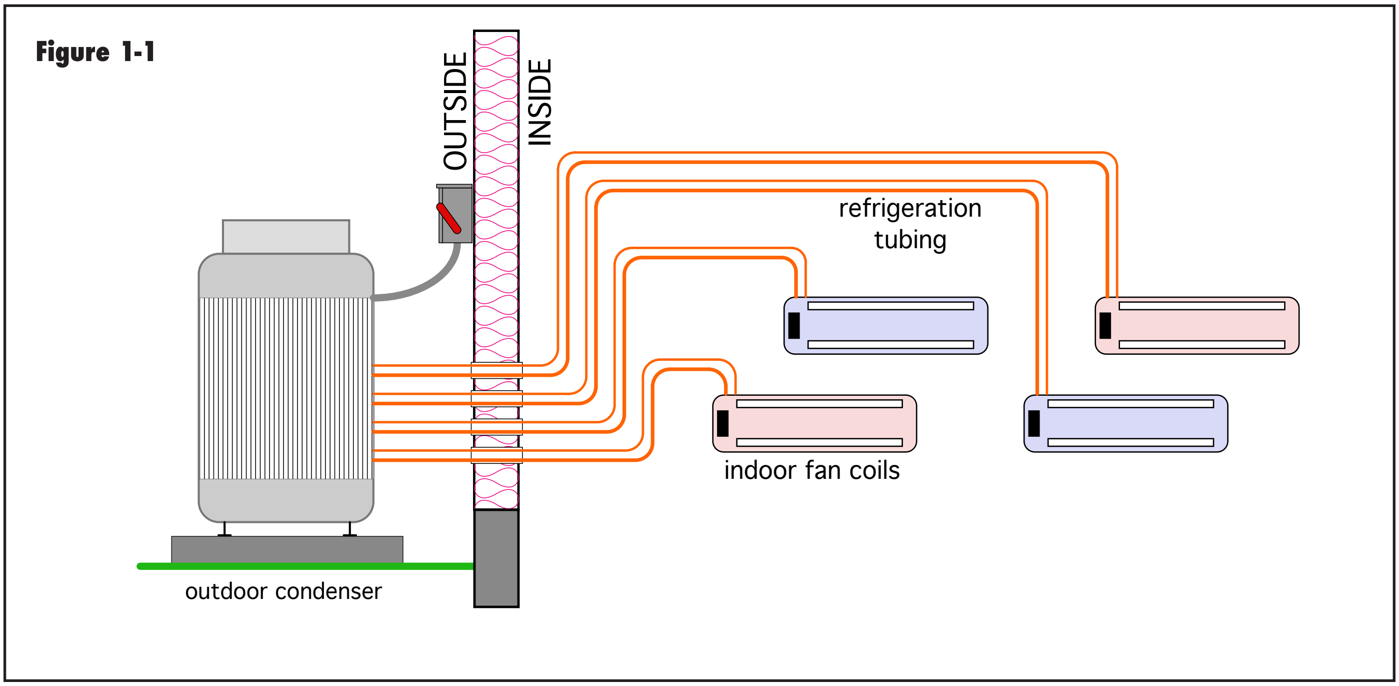
Early generation air-to-air heat pumps were not able to maintain efficient operation at low outdoor air temperatures. They became ineffective when outdoor temperatures dropped below 20ºF. Under those conditions, an auxiliary heat source such as a furnace or electric-resistance heating elements contained in the indoor portion of the heat pump were turned on to supply the building's heating load.

This inability to provide sufficient performance at low outdoor temperatures was the "Achilles heal" of early air-source heat pumps. This limitation established a long-held perception that air-source heat pumps could not be used in cold winter climates.

Fortunately, this performance limitation is quickly changing. Advances in refrigeration technology, including techniques used in SpacePak Solstice heat pumps, now allow air-source heat pumps to operate at very low outdoor temperatures — in some cases down to -8ºF (-22ºC).

Many of the largest global providers of heating and cooling hardware now offer "cold climate" or "low-ambient" versions of air-to-air heat pumps. The most common configuration is called a "ductless" or "mini-split" heat pump system. A single outdoor unit connects to multiple indoor wall-mounted air handlers, each supplied by its own refrigeration line set. Each indoor air handler can operate independently, allowing for zoning. The concept is shown in Figure 1-1.

Although these cold-climate air-to-air heat pumps represent a growing market, they rely on *forced-air* delivery for heating and cooling. As such, they don't offer the ability to serve loads other than space heating and cooling. They also lack the ability to provide *radiant* as well as convective heat input to interior spaces. As such, they are not as well-matched to human physiological comfort requirements in comparison to some hydronic heating systems that deliver both radiant and convective heat.



Air-source heat pumps + hydronics:

Modern hydronics technology can adapt to many types of heating and cooling loads. It's also known for delivering *unsurpassed comfort*. Several types of heat sources can be used individually or in combination to create heated water from a variety of energy sources.

Hydronic systems can provide space heating, domestic water heating, and pool heating. Chilled-water hydronic systems can also provide cooling and dehumidification.

The electrical "distribution energy" required by a hydronic system to move heat (or cooing effect) throughout a building is far less than that required by a forced-air system of equal capacity.

Consider a scenario in which the advantages of a modern air-source heat pump are combined with the benefits of a *hydronic* distribution system. The result would be an *air-to-water* heat pump system. When operating in heating mode, this heat pump would absorb low-temperature heat from outside air and deliver higher-temperature heat to one or more loads using a stream of water (or water/antifreeze solution). When operating in cooling mode, the heat pump would deliver a stream of chilled water (or water/antifreeze solution) to cool the building.

Some modern air-to-water heat pumps can produce water temperatures up to 130ºF, even when the source is cold outdoor air. This allows for the use of a wide range of hydronic heat emitters, including radiant floor, wall, and ceiling panels; panel radiators, fan-coil convectors, and contemporary low-temperature fin-tube baseboard. It also allows the heat pump system to provide most, if not all, of the heat required for domestic hot water. With a suitable heat exchanger, heat can also be supplied to a swimming pool, or to melt snow on steps, a patio, or a sidewalk.

In cooling mode, air-to-water heat pumps can produce chilled-fluid temperatures as low as 42ºF. This fluid can be routed to terminal units such as a central air handler or multiple high-wall air handlers located in different building zones. With suitable controls, the chilled fluid can also be delivered to chilled beams or radiant panels located in ceilings, walls or floors. Combinations of these terminal units are also possible.

These concepts greatly extend the potential applications for air-source heat pumps.

2. SOLSTICE SE AND SOLSTICE EXTREME HEAT PUMPS

SpacePak Corporation currently offers two versions of air-to-water heat pumps. Both are self-contained units (e.g., the entire heat pump is housed in a single exterior cabinet). Both can provide heating and cooling.

The *Solstice SE*, shown in Figure 2-1, is a two-stage heat pump available in two nominal heating capacities of 36,000 Btu/hr or 60,000 Btu/hr.

Figure 2-1

The *Solstice SE* SCM-036 air-to-water contains two separate refrigeration circuits, each rated at a nominal 18,000 Btu/hr (1.5 tons) of heating capacity. Each refrigeration circuit can operate independently. When heating or cooling loads are minimal, only one refrigeration circuit needs to operate. As loads increase, the other refrigeration circuit automatically turns on. The controller within the heat pump determines which of the two refrigeration circuits needs to operate to maintain a user-specified leaving water temperature.

Two-stage operation allows better matching between heat output and variable heating loads. This reduces compressor cycling under partial load conditions, which improves performance and increases life expectancy. It also allows the heat pump to provide a higher heating capacity in winter in combination with a lower cooling capacity in summer, which is a common requirement for heat pump systems.

The Solstice SE SCM-060 contains two refrigeration systems, each rated at a nominal heating capacity of 30,000 Btu/hr (2.5 tons). Other than its higher heating and cooling capacity, the SCM-060 operates the same as the SCM-036.

Both models of the Solstice SE heat pump can operate in ambient temperatures as low as 15ºF.

The *Solstice Extreme* air-to-water heat pump is shown in Figure 2-2. It is a single stage "low-ambient" air-to-water heat pump with a nominal 48,000 Btu/hr rated heating capacity. The Solstice Extreme can operate in outdoor temperatures as low as -8ºF, and produce water temperatures as high as 130ºF.

Later sections of the manual will show how to integrate both the Solstice SE and Solstice Extreme heat pumps into systems.

Figure 2-2

3. OPERATING CHARACTERISTICS OF AIR-TO-WATER HEAT PUMPS

Most air-to-water heat pumps operate on a vapor compression cycle. This cycle is based on circulating a refrigerant, such as R-410a, through a closed circuit containing devices such as a compressor, two heat exchangers and an expansion device.

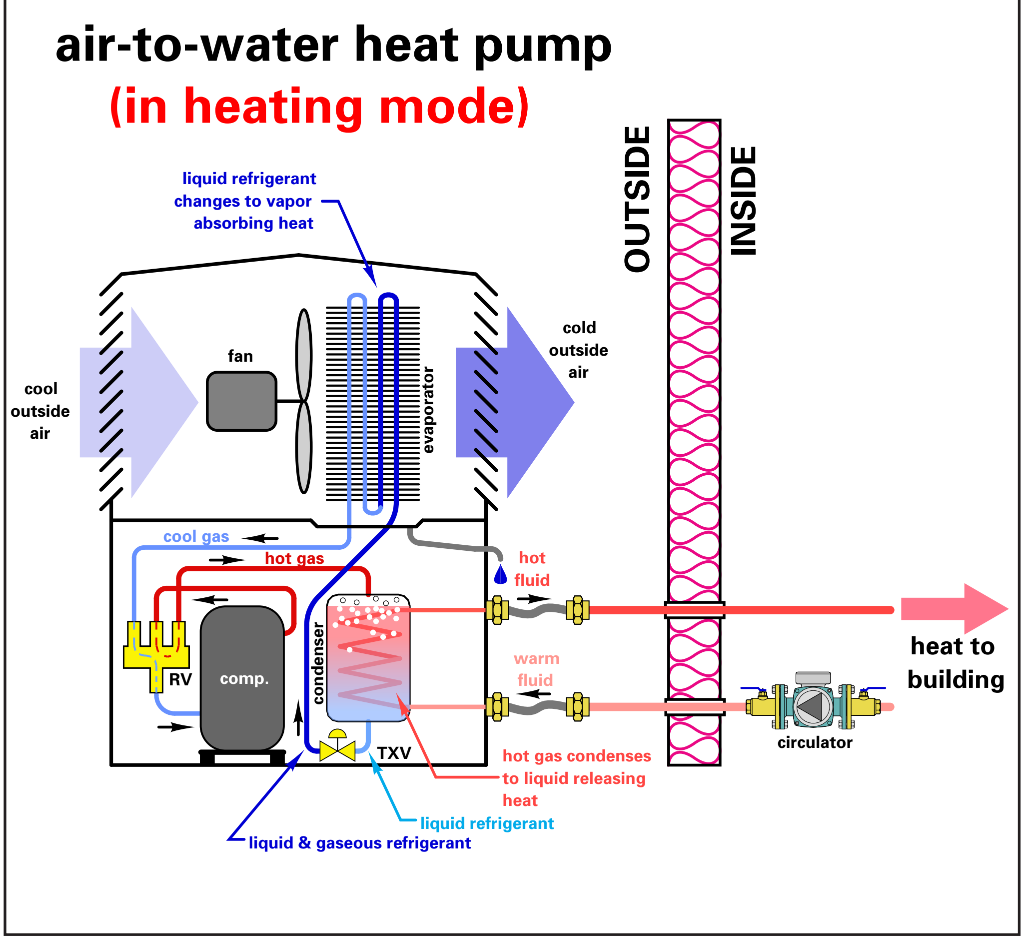
Although the refrigerant cycle used in an air-to-water heat pump is similar to that used in devices such as refrigerators, freezers and water coolers, there are important differences. One is that heat pumps are "reversible." They can be used to produce heat for a heating load, or to remove heat to meet a cooling load.

Heating mode operation:

Figure 3-1 shows the basic components used to operate a vapor compression cycle in an air-to-water heat pump operating in heating mode.

Liquid refrigerant at a low temperature passes through a heat exchanger called the *evaporator*, seen near the top of Figure 3-1. It absorbs low temperature heat from outside air, which is blown across the evaporator by a fan. The absorbed heat causes the refrigerant to change from liquid to vapor. This cool vapor passes through a reversing valve, and on to an electrically driven compressor. Its pressure and temperature are greatly increased as it passes through the compressor. The hot refrigerant vapor exits the compressor, does a "U-turn" through the reversing valve, and enters another heat exchanger called the *condenser*. A stream of water or an antifreeze solution, propelled by a circulator, passes through the other side of the condenser. The hot refrigerant vapor transfers heat to this fluid, and in the process, condenses from vapor back into a liquid. The liquid refrigerant then passes through a thermal expansion valve (labeled as TXV in Figure 3-1), where its pressure and temperature are reduced to the condition where this cycle description began. The refrigerant contained within the heat pump is constantly flowing through this cycle whenever the heat pump is operating.

Figure 3-1



The useful output of operating an air-to-water heat pump in heating mode is a stream of heated water (or water-based antifreeze solution) that circulates through a hydronic heating distribution system within the building, or through other devices that heat domestic water, heat a pool or provide heat for another specialized purpose such as root zone heating in a greenhouse.

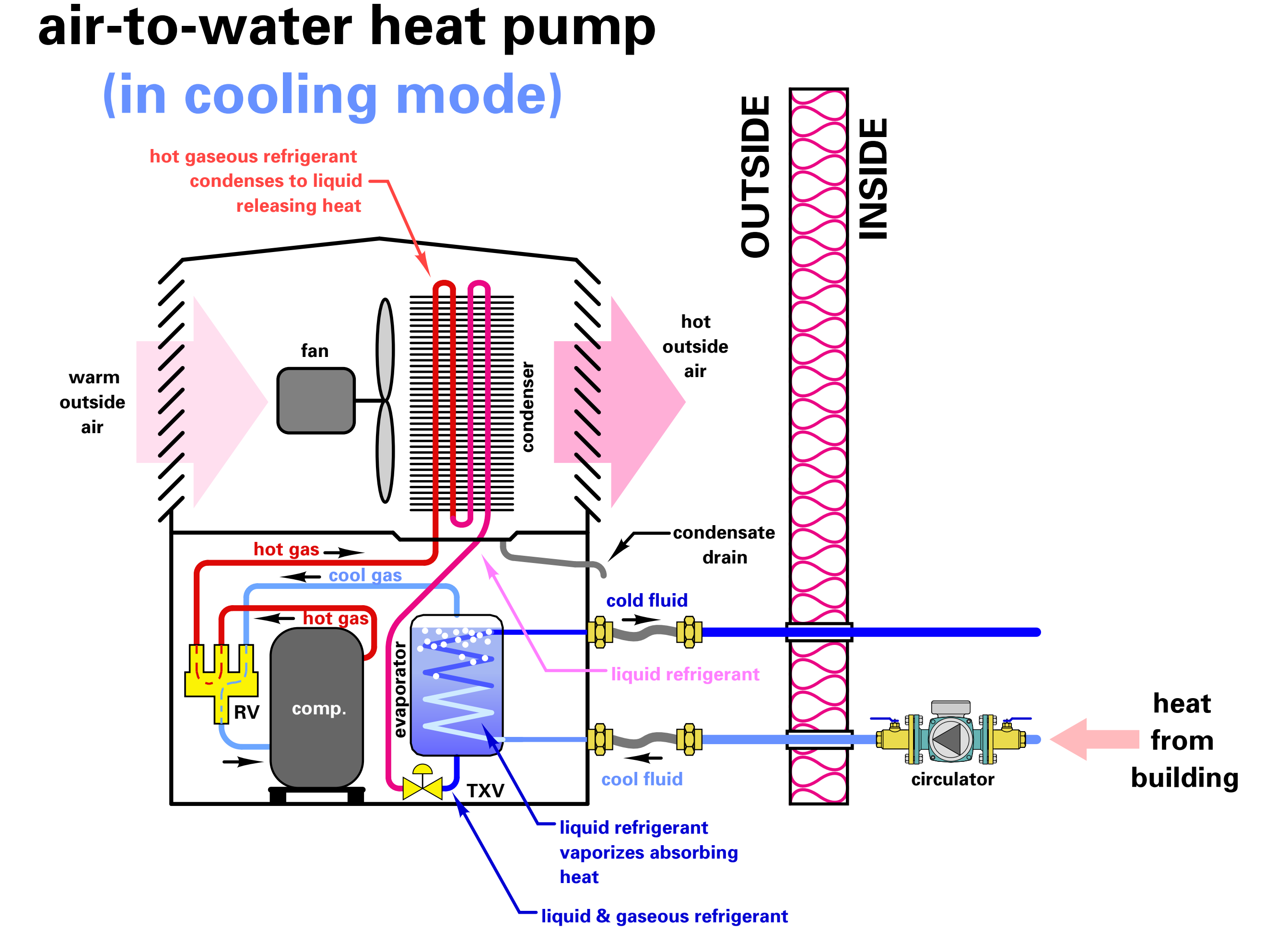
Cooling mode operation:

In cooling mode, heat is absorbed from a stream of water (or water-based antifreeze solution) being propelled through the heat pump by a circulator. This heat is eventually rejected to outside air.

In cooling mode, the functions of the two heat exchangers in the refrigerant circuit are reversed compared to when the heat pump operates in heating mode. The heat exchanger that served as the evaporator in the heating mode becomes the condenser in cooling mode. The heat exchanger that served as the condenser in heating mode becomes the evaporator in cooling mode. This "swapping" between the heat exchangers is accomplished using an electrically operated reversing valve (RV), which can be seen in the lower left corner of the heat pump in Figure 3-2.

The useful output of an air-to-water heat pump operating in cooling mode is a stream of chilled water (or water-based antifreeze solution) that circulates through a hydronic distribution system within the building to provide cooling and dehumidification.

Figure 3-2



Heating Capacity & COP:

The two performance indices for heat pumps operating in heating mode are:

a. Heating capacity
b. Coefficient of performance (COP)

The heating capacity of a heat pump is the rate at which the heat pump can deliver heat to the load. In North America, this is expressed in units of Btu/hr. The “rated” heating capacity of a heat pump is based on specified operating conditions, and is usually based on an industry standard. The heating output the heat pump delivers at any given time could be higher or lower than the rated heating capacity, depending on the current operating conditions in comparison to the rated operating conditions. This variation in heating capacity is characteristic of all heat pumps, and needs to be carefully evaluated by the designer.

The coefficient of performance, or COP, of a heat pump is the ratio of the heat output rate divided by the energy input rate to operate the heat pump.

If the heat output rate and corresponding electrical power demand of a heat pump can be accurately measured, the instantaneous COP of the heat pump can be calculated using Formula 3-1.

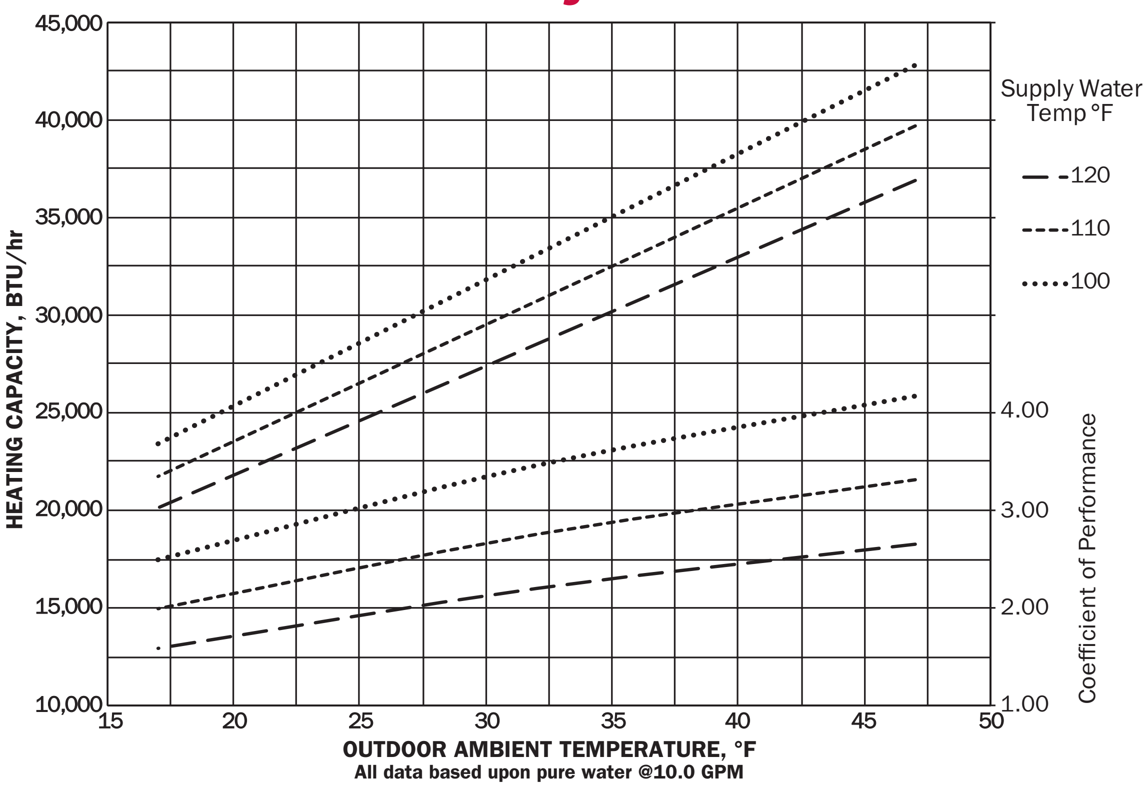
Formula 3-1:

$$COP=\frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413}$$

COP can also be thought of as the number of units of useful energy output the heat pump delivers, per unit of energy input. For example, a heat pump operating at a COP of 3.0 would deliver 3 units of useful heat output for each unit of energy input.

Figure 3-3

SCM-036 Heating Performance



The higher the COP, the greater the usable heat output produced for a given rate of energy input. The system in which a heat pump will be used should always be designed to achieve and maintain operating conditions that keep the COP of the heat pump as high as possible.

Both the COP and heating capacity of any heat pump are highly dependent on the temperature of the source.

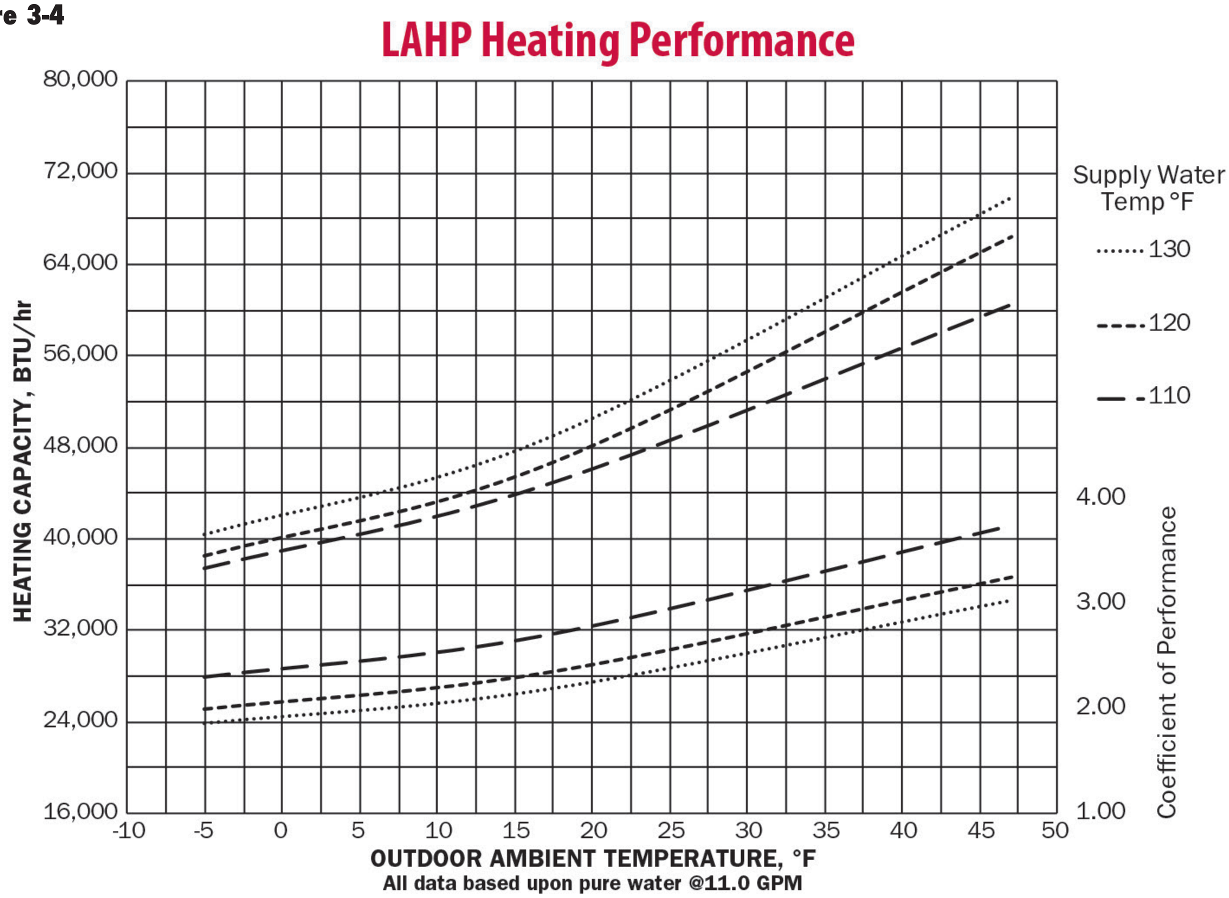
For an air-to-water heat pump operating in heating mode, the source of low-temperature heat is outside air. *As the outdoor air temperature decreases, so does the heat pump's heat capacity. Heating capacity also decreases as the water temperature leaving the condenser of the air-to-water heat pump increases.* Figure 3-3 shows the relationship between heating capacity, COP as a function of outdoor air temperature and leaving water temperature for the Solstice SE SCM-036 heat pump.

When the outdoor temperature is 45ºF, and the Solstice SE SCM-036 is supplying 110ºF water to a load, its heating capacity is about 38,000 Btu/hr, and its COP is about 3.25. However, if the outdoor temperature is 20ºF, and the water temperature to the load remains at 110ºF, the heating capacity decreases to 23,500 Btu/hr, and the COP decreases to about 2.15.

Figure 3-4 shows the relationship between heating capacity, COP as a function of outdoor air temperature and leaving water temperature for the Solstice Extreme heat pump.

The heating capacity and COP of the Solstice Extreme also decrease as outdoor temperature drops. However, the Solstice Extreme heat pump can remain in operation at significantly lower outdoor temperatures compared to the Solstice SE. This makes the Solstice Extreme model well-suited to cold-climate applications.

Figure 3-4



System designers should also understand that the *flow rate* of water or an antifreeze solution through the condenser of an air-to-water heat pump also affects its heating capacity and COP. The "rated" heating capacity and COP of a heat pump are based on some specified water flow rate through the heat pump's condenser. Increasing condenser flow rate above the rating condition value will increase heating capacity and COP, and vice versa. Higher flow rates reduce the temperature rise across the condenser and allow for tighter temperature control.

System designers should select piping and appropriate circulators so that flow rates through a Solstice SE or Solstice Extreme heat pump remain within the range specified in the Installation & Operation (I/O) manual.

Cooling performance:

The ability of an air-to-water heat pump to chill water for space cooling also depends on operating conditions. The most influential are the water temperature leaving the heat pump's evaporator and the temperature of outdoor air entering the heat pump's condenser.

The two indices used to describe the cooling performance of an air-to-water heat pump are:

a. Cooling capacity
b. Energy Efficiency Ratio (EER)

Cooling capacity is the rate at which the heat pump absorbs heat from the water stream passing through its evaporator. The *rated* cooling capacity gives the rate of heat absorption under specific operating conditions, such as 44ºF leaving chilled-water temperature, and 95ºF outdoor dry bulb temperature. The cooling capacity at any given time could be higher or lower than the *rated* cooling capacity based on the conditions under which the heat pump is operating.

The cooling capacity of any heat pump increases when the temperature of the source media (e.g., the material from which heat is being absorbed) increases. Cooling capacity also increases when the temperature of the sink media (e.g., the material to which heat is rejected) decreases.

For an air-to-water heat pump, cooling capacity decreases as the temperature of the chilled water leaving its evaporator decreases. Cooling capacity also decreases as the outdoor air temperature increases. Designers have very little control over outdoor air temperature, but do have some control over the chilled-water temperature required by the cooling distribution system. The higher the chilled-water temperature can be and still meet the building's cooling and dehumidification requirements, the higher the heat pump's cooling capacity.

Energy Efficiency Ratio:

In North America, the common way of expressing the instantaneous cooling efficiency of a heat pump is called Energy Efficiency Ratio (EER), which is defined by Formula 3-2:

Formula 3-2:

$$\text{EER}=\frac{Q_c}{w_e}=\frac{\text{cooling capacity (Btu/hr)}}{\text{electrical input wattage}}$$

Where:

EER = Energy Efficiency Ratio
Q_c = cooling capacity (Btu/hr)
W_e = electrical power input to heat pump (watts)

The higher the EER of a heat pump, the lower the electrical power required to produce a given rate of cooling.

Like COP, the EER of a heat pump is a function of the source and sink temperatures. The warmer the source media is compared to the sink media temperature, the higher the heat pump's EER. To maximize EER, designers of chilled-water cooling systems using air-to-water heat pumps should use the highest possible chilled-water temperature that still allows adequate cooling and dehumidification.

Cooling capacity and EER are also affected by the flow rate of water through the heat pump's evaporator. Flow rates that are higher than the rated flow rate will increase both cooling capacity and EER, and vice versa. Higher flow rates reduce the temperature drop across the evaporator and allow for tighter temperature control.

Flow rates through a Solstice SE or Solstice Extreme heat pump should remain within the range specified in the Installation & Operation (I/O) manual.

Tonnage:

In North America, the heating or cooling capacity of heat pumps has been customarily described using the units of "tons". In this context, a ton describes a *rate* of heat flow, of 12,000 Btu/hr. Thus, a "3-ton" heat pump implies it has a nominal heating or cooling capacity of 3 x 12,000 or 36,000 Btu/hr.

The "tonnage" of a heat pump has nothing to do with its weight. The term "ton" was derived from the early days of refrigeration. At a rate of 12,000 Btu/hr, one ton of ice melts into 32ºF water over a period of 24 hours.

The tonnage of a heat pump is a *nominal* rating at some specific set of operating conditions. Thus, a "3-ton" rated heat pump could produce a heat output significantly higher than 3 tons when operated under more favorable conditions, and significantly less than 3 tons when operated under less favorable conditions.

4. LOW-TEMPERATURE HEAT EMITTER OPTIONS

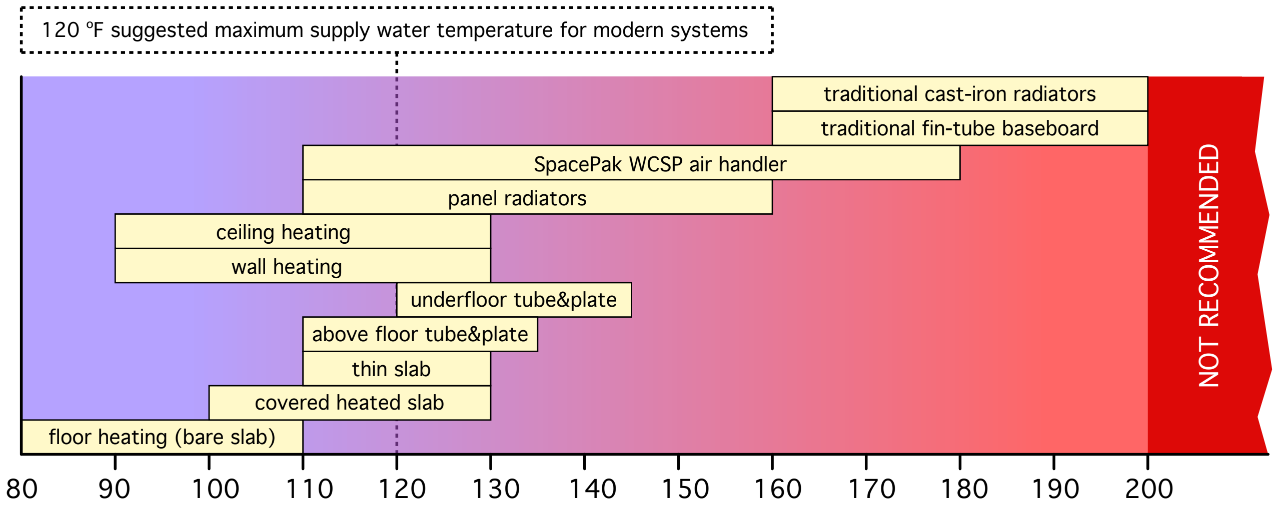
Section 3 discussed how the heating capacity and COP of Solstice heat pumps increase as the water temperature leaving the heat pump's condenser decreases. *To achieve the best possible heating performance from Solstice heat pumps, it's imperative to combine them with heat emitters that can operate at the lowest possible water temperature.*

Figure 4-1 shows the 'traditional" water temperature range for several types of hydronic heat emitters.

A suggested criterion for modern hydronic heating system design is to create hydronic distribution systems that can deliver design heating output using a supply water temperature no higher than 120ºF.

The 120ºF supply water temperature is achievable by both Solstice SE and Solstice Extreme air-to-water heat pumps. This suggested criterion also recognizes that the distribution piping and heat emitters in a well-planned and properly installed hydronic system should last many decades. The distribution system will likely outlast its first heat source, and perhaps even its second or third heat source. It only makes sense to create distribution systems that are likely to remain compatible with future low-temperature heat sources.

Figure 4-1



Fortunately, there are several heat emitter options, many of which are available from SpacePak, that allow these criterion to be achieved in a wide range of systems.

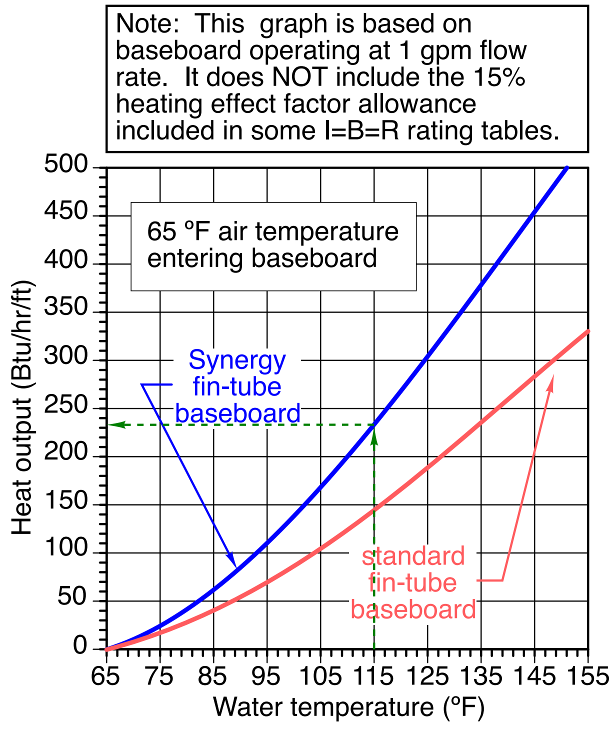
Low-temperature fin-tube baseboard:

One option is the use of "low-temperature" finned-tube baseboard such as Synergy baseboard from Mestek. Synergy baseboard uses substantially larger aluminum fins for its heating element relative to common residential-style baseboard.

Figure 4-2 shows the output of Synergy baseboard (shown as the blue curve), compared to standard residential fin-tube baseboard (shown as the red curve).

At an average water temperature of 115°F, Synergy baseboard releases about 230 Btu/hr per foot of element length. By comparison, a foot of standard baseboard element releases about 145 Btu/hr. Thus, the Synergy baseboard provides about 59% greater heat output for the same element length at the stated operating conditions.

Figure 4-2



Fan-coils:

Another heat emitter option is a fan-coil unit. Warm water passes through the heat exchanger "coil" within this emitter. Room air is blown across the aluminum fins of the coil to transfer heat to the room air.

Fan-coils are available in several configurations. One common type is called a "high-wall" fan-coil. An example of the *SpacePak HighWall* fan-coil is shown in Figure 4-3.

Figure 4-3

The SpacePak HighWall fan-coil can be used for heating or cooling. It has a blower driven by a highly efficient electronically commutated variable-speed motor to deliver quiet air flow. A motorized damper at the air outlet of the unit slowly oscillates to mix the discharge air stream with room air. SpacePak HighWall fan-coils are available in three heating capacity ranges and can operate with heating water temperatures as low as 120°F. They are also equipped with condensate drip pans, allowing them to be used for chilled-water cooling.

Ducted air handlers:

Ducted air handlers are also available from SpacePak. They are typically mounted above a ceiling or below a floor. Air discharged from these units is routed through multiple branch ducts for delivery at several locations within a building.

Figure 4-4 shows the SpacePak WCSP series air handler. It's available in 3 sizes and capacity ranges, which can provide between 25,000 and 70,000 Btu/hr of heating with inlet water temperatures of 120°F supply water.

The WCSP series air handler is connected to a high static-pressure ducting system that serves multiple air outlets through small, 2-inch diameter, insulated flexible ducting.

Figure 4-4

Figure 4-5 shows the typical components in such a duct system.

This duct system can be used to deliver warm air for heating or cooled/dehumidified air for cooling.

The WCSP-J air handler is equipped with condensate pans and drains for use in chilled-water cooling systems. Cooling capacities are a function of the chilled-water temperature and flow rate entering the coil, as well as the dry bulb temperature, relative humidity, and air flow rate across the coil. Cooling capacity increases with increased water flow and air flow rates. It also increases as the temperature of entering chilled-water decreases. The cooling capacity of the three available WCSP-J air handlers varies from approximately 21,000 to 51,000 Btu/hr when operating with an inlet water temperature of 45ºF.

The installation and operating manuals for these air handlers gives specific heating and cooling capacities as functions of entering air temperature, entering water temperature and flow rates.

Figure 4-6 shows the heating and cooling capacities of the three WCSP ducted air

Figure 4-5

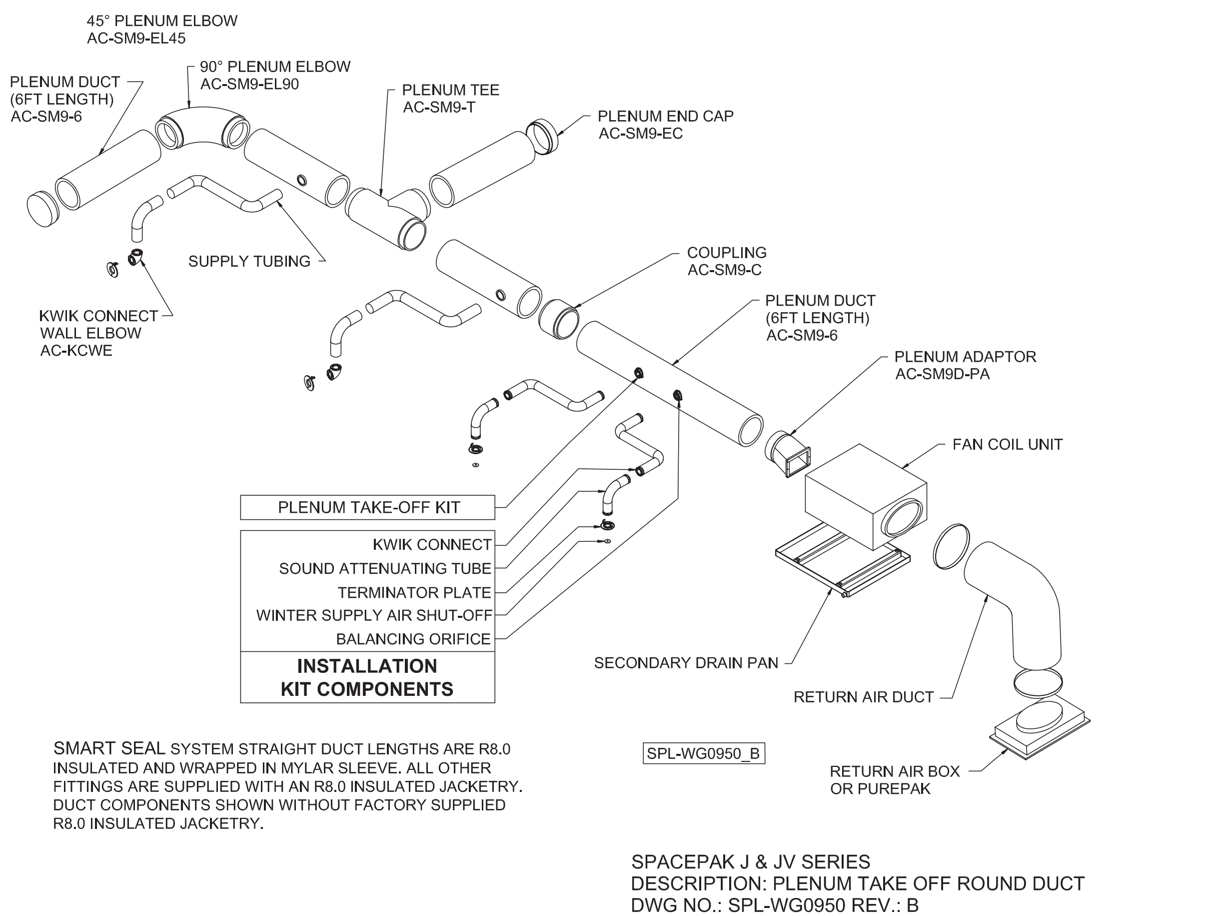
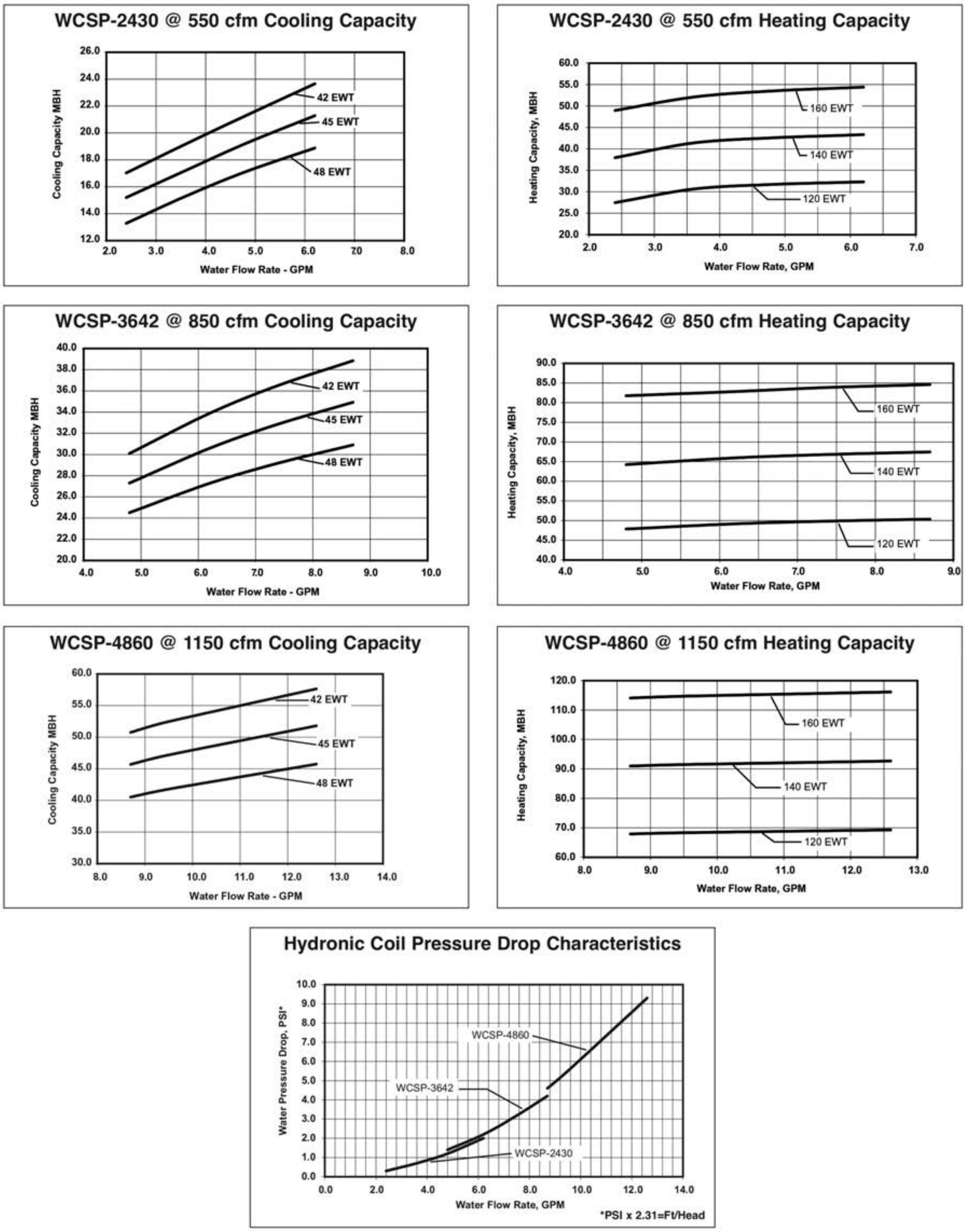


Figure 4-6



WCSP-2430 @ 550 cfm Cooling Capacity
Cooling Capacity MBH
Water Flow Rate - GPM
42 EWT
45 EWT
48 EWT
WCSP-2430 @ 550 cfm Heating Capacity
Heating Capacity, MBH
Water Flow Rate, GPM
160 EWT
140 EWT
120 EWT
WCSP-3642 @ 850 cfm Cooling Capacity
Cooling Capacity MBH
Water Flow Rate - GPM
42 EWT
45 EWT
48 EWT
WCSP-3642 @ 850 cfm Heating Capacity
Heating Capacity, MBH
Water Flow Rate, GPM
160 EWT
140 EWT
120 EWT
WCSP-4860 @ 1150 cfm Cooling Capacity
Cooling Capacity MBH
Water Flow Rate - GPM
42 EWT
45 EWT
48 EWT
WCSP-4860 @ 1150 cfm Heating Capacity
Heating Capacity, MBH
Water Flow Rate, GPM
160 EWT
140 EWT
120 EWT
Hydronic Coil Pressure Drop Characteristics
Water Pressure Drop, PSI*
Water Flow Rate, GPM
WCSP-4860
WCSP-3642
WCSP-2430
*PSI x 2.31=Ft/Head

handlers at three nominal air flow rates: 550, 850, and 1150 CFM. The heating and cooling capacities are a function of entering water temperature and water flow rate.

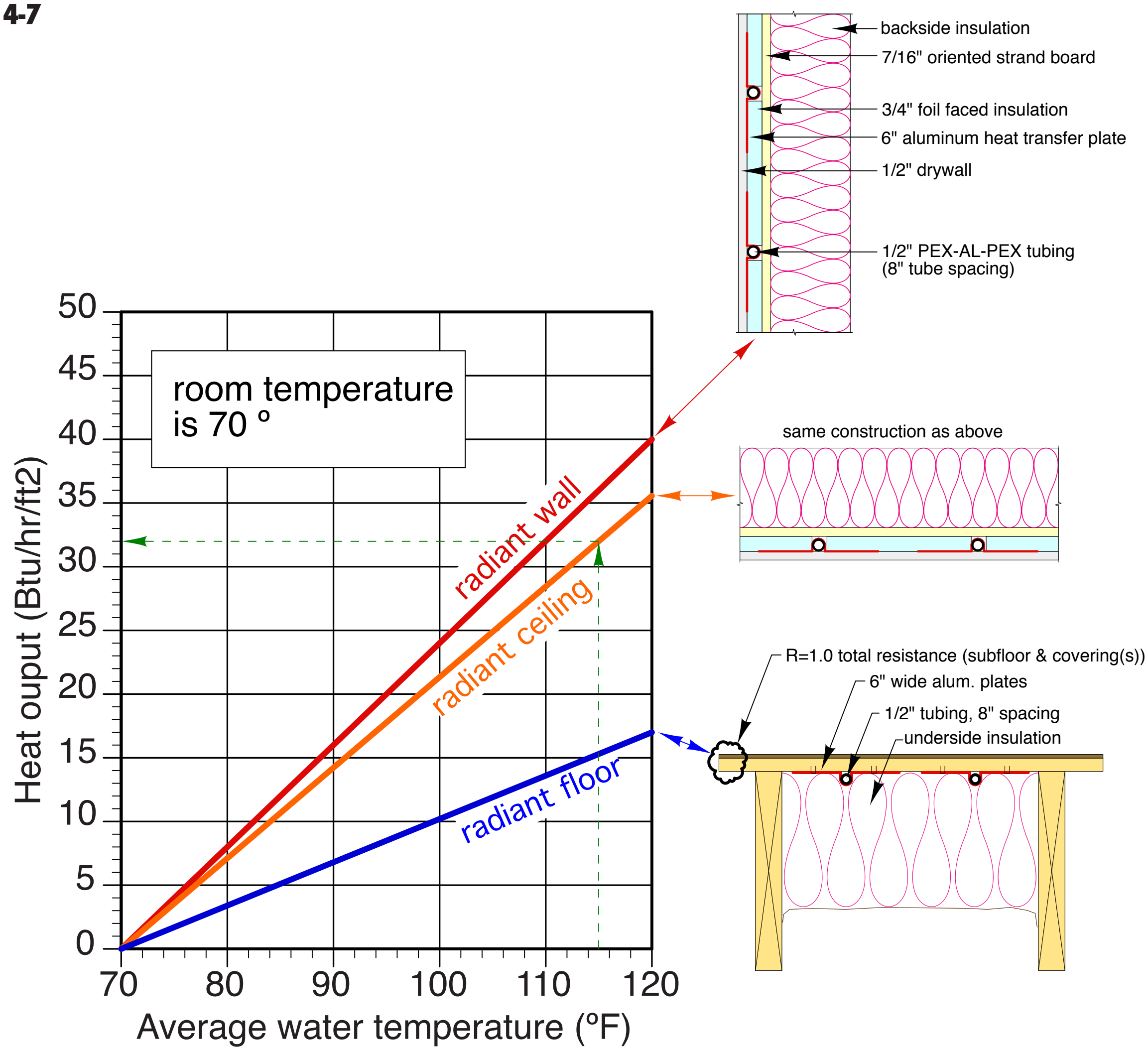
Radiant panels:

Radiant panels represent another category of low-temperature heat emitters. It includes radiant *floor* heating as well as radiant *wall* and radiant *ceiling* heating. There are several variations within each category. For example, radiant floors can be integrated into slab-on-grade construction, or into framed-floor construction. Some radiant panels can operate at supply water temperatures under 100ºF, even at design load conditions. These low-temperature radiant panels are especially suitable for use with Solstice air-to-water heat pumps.

Figure 4-7 shows the room-side heat output of three specific types of radiant panels:

• A radiant wall panel
• A radiant ceiling panel
• A bottom-side tube & plate radiant floor panel

Figure 4-7



These outputs are specific to the construction details for each panel. Panels with different construction and tube spacing will have different outputs.

The room-side heat output of each radiant panel represented in Figure 4-7 is given in Btu/hr/ft^2. For example, the radiant *ceiling* panel represented in Figure 4-6 releases approximately 22 Btu/hr/ft^2 into a 70ºF room below when operated at an average water temperature of 100ºF. Under the same conditions, the radiant *wall* panel releases about 24 Btu/hr/ft^2, and the radiant floor panel represented releases about 10 Btu/hr/ft^2. The total heat output of the panel is determined by taking the Btu/hr/ft^2 output and multiplying by the total area of the panel.

There are many other types of radiant panels. A heated concrete slab-on-grade floor panel, for example, can produce a given room-side heat output while operating at lower water temperatures relative to the bottom side tube & plate panel represented in Figure 4-8. More information on the construction options and thermal performance of radiant panels is available in Reference 1 listed in Appendix C.

Panel radiators:

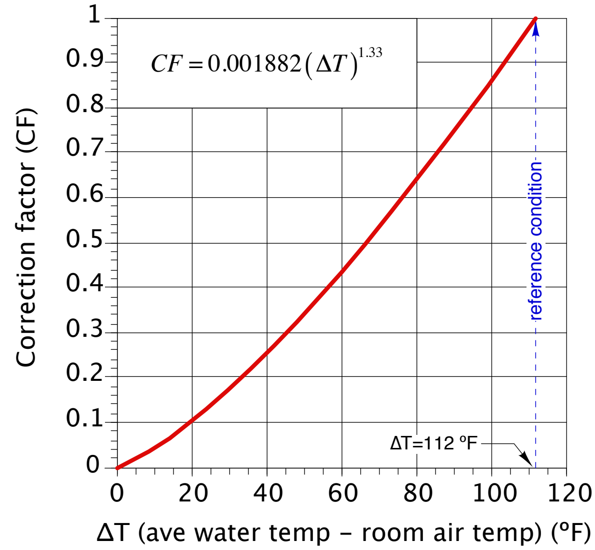
Although their origins are in Europe, panel radiators are now available in North America from several suppliers. A wide range of products are available ranging from "utility-type" fluted-steel panel radiators, shown in Figure 4-8, to eye-catching aesthetic panels that are often construed as art rather than functional heat emitters.

Most of the panel radiators sold in North American are constructed of steel, and as such must be use is *closed-loop* hydronic systems. Most panel radiators have relatively low thermal mass, allowing them to quickly increase or decrease heat output as the water passing through them changes temperature. Panel radiators are available in different heights, widths and thicknesses to provide a reasonable match between panel output and room heating load, while also fitting radiators into constrained spaces such as below windows or in alcoves.

The "rated" output of panel radiators is often based on relatively high average water temperatures, such as 180ºF. Most manufacturers provide correction factors such as those shown in Figure 4-9 to adjust for low average water temperatures.

Figure 4-8

Figure 4-9



Reference condition:
Ave water temperature in panel = 180ºF
Room air temperature = 68ºF

If panel radiators are to be selected based on a supply water temperature of 120ºF, the average water temperature used to establish the correction factor should be approximately 110ºF (assuming the panel operates with a nominal 20ºF temperature drop under design load conditions). As a guideline, the heat output of a panel radiator operating at an average water temperature of 110ºF is about 25% of its heat output when operated at an average water temperature of 180ºF.

Panel radiators sized to provide a given heat output while operating at relatively low average water temperatures must be larger than panels operated at significantly higher average water temperatures.

Fan-assisted panel radiators:

Another option in low water-temperature heat emitters is known as a fan-assisted panel radiator. It uses several low-voltage "micro-fans" and a deep fin-tube element to substantially boost convective heat output under low water-temperature operation. It also provides radiant heat output from its room-side surface.

Many panel radiators can be equipped with non-electric thermostatic valves that can adjust the flow rate through the radiator in response to room air temperature. This allows each panel to operate as a separate zone within the overall heating system. This approach will be described in the next section of this manual.

5. DISTRIBUTION SYSTEM PIPING

There are many ways in which multiple heat emitters can be combined to create a heating distribution system for a building. One of the simplest approaches that can be used to connect multiple fin-tube baseboards, fan-coils or panel radiators is called a *homerun* distribution system.

In homerun systems, each heat emitter is supplied from a manifold station. The supply and return tubing between this manifold station and each heat emitter is typically 1/2" PEX, PERT or PEX-AL-PEX. This flexible tubing is easily routed through and along framing cavities in walls, ceilings and floors, between the mechanical room and each heat emitter. The routing is analogous to pulling electrical cable through a building, and is especially beneficial in retrofit installations.

Figure 5-1 shows an example of a homerun distribution system where several Synergy baseboards, each equipped with a thermostatic radiator valve, are connected into a distribution system.

Figure 5-1 shows an angle pattern thermostatic radiator valve installed on the <u>*inlet*</u> side of each Synergy fin-tube baseboard.

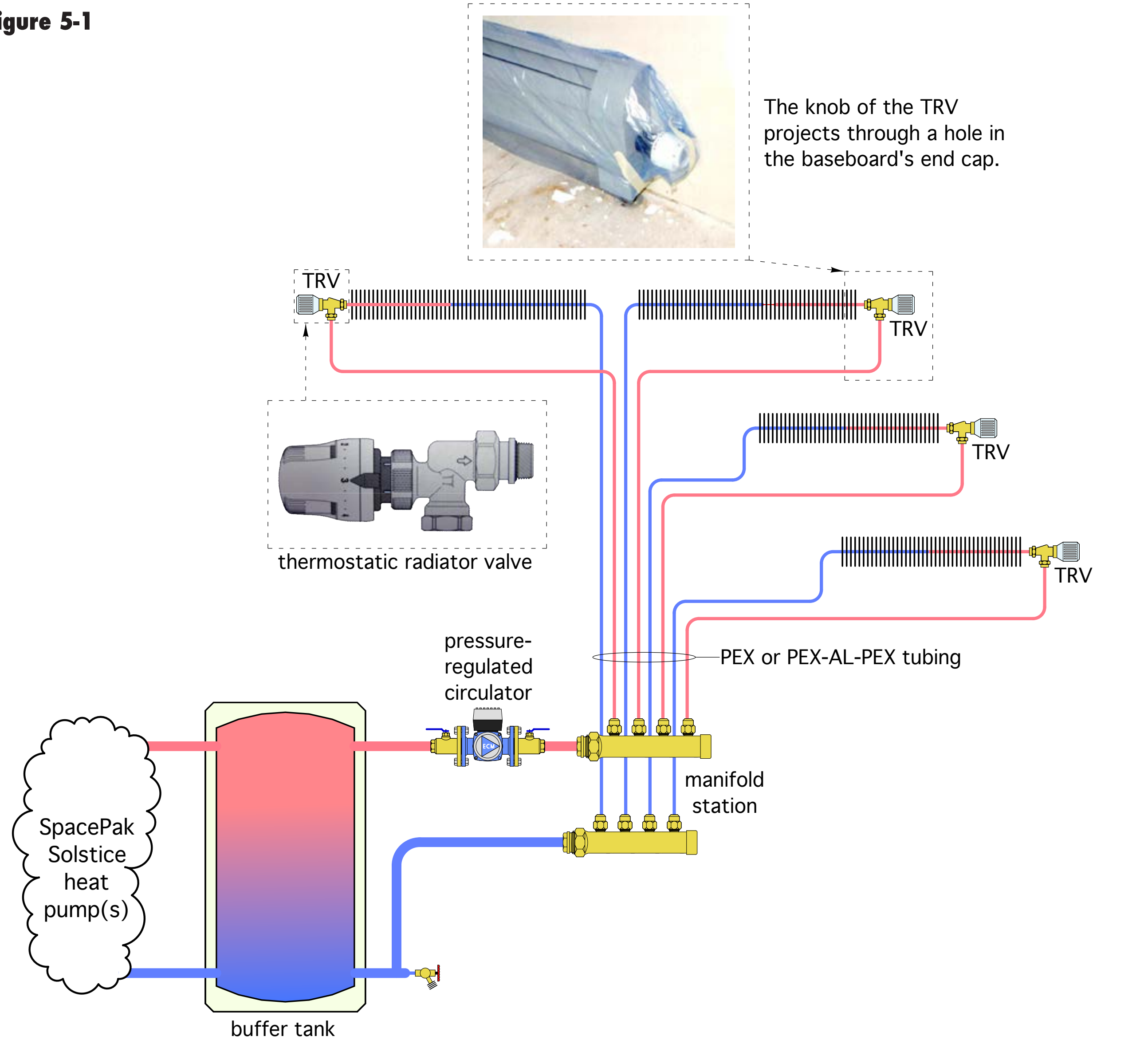
Figure 5-2 shows another homerun distribution system where several panel radiators, each equipped with a thermostatic radiator valve, are used.

It's also possible to *combine* low-temperature fin-tube baseboard and panel radiators into the same homerun distribution system. *This requires that all the heat emitters are sized for their required heat outputs at the same supply water temperature.* Radiant panel circuits for floors, walls and ceilings can also be supplied from the same manifold station if their supply water temperature requirement is the same as that of the fin-tube baseboards or panel radiators.

The distribution systems shown in Figures 5-1 and 5-2 include a buffer tank and a variable-speed pressure-regulated circulator.

The buffer tank allows a single stage heat pump, such as the Solstice Extreme, to achieve adequately long on-cycles, even when only one heat emitter is operating. This improves heat

Figure 5-1



pump performance and longevity relative to systems when the heat pump is forced to short cycle due to minimal loading.

The variable-speed pressure-regulated circulator is set to maintain a constant differential pressure between the supply and return manifolds supplying the homerun circuits to each heat emitter. This helps maintain consistent flow through each operating heat emitter regardless of what heat emitters are on or off. The variable-speed circulator also reduces its electrical power demand when it operates at reduced flow rates.

Flow through each homerun circuit can also be controlled using a manifold station equipped with individual circuit valves and manifold valve actuators. The concept is shown in Figure 5-3.

Figure 5-2

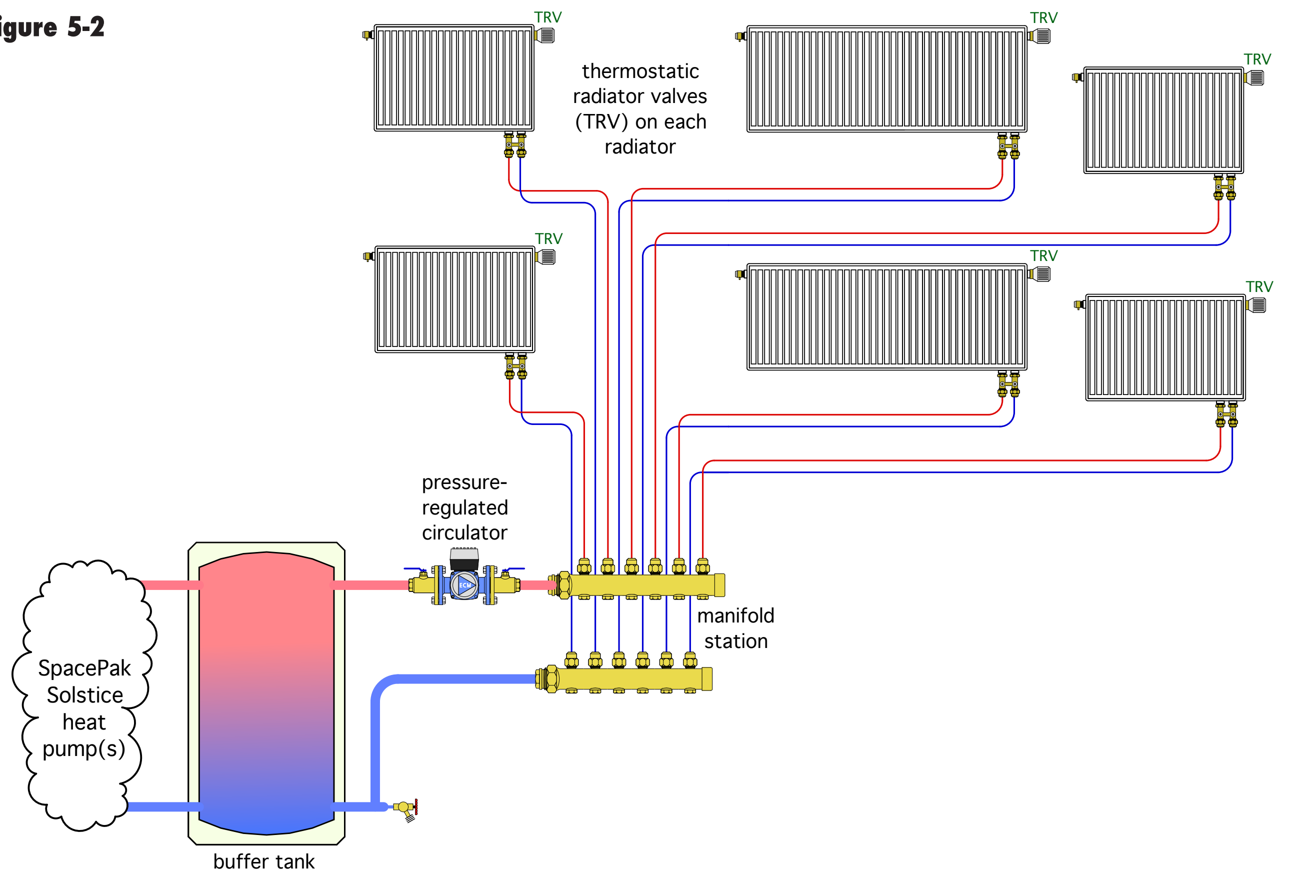
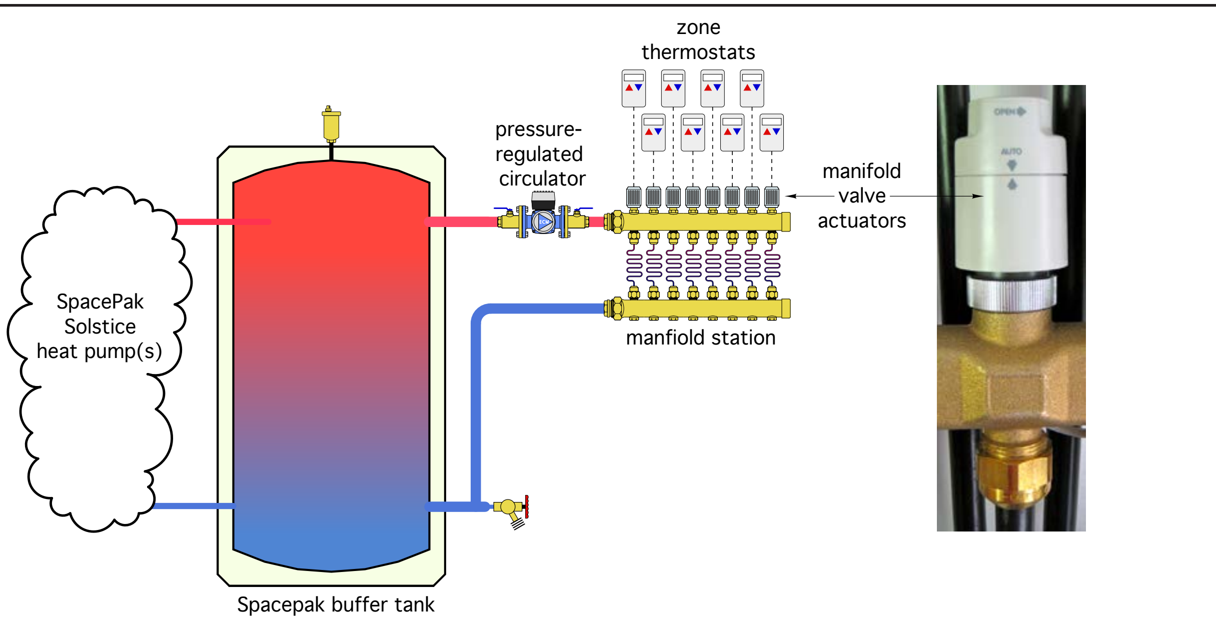


Figure 5-3

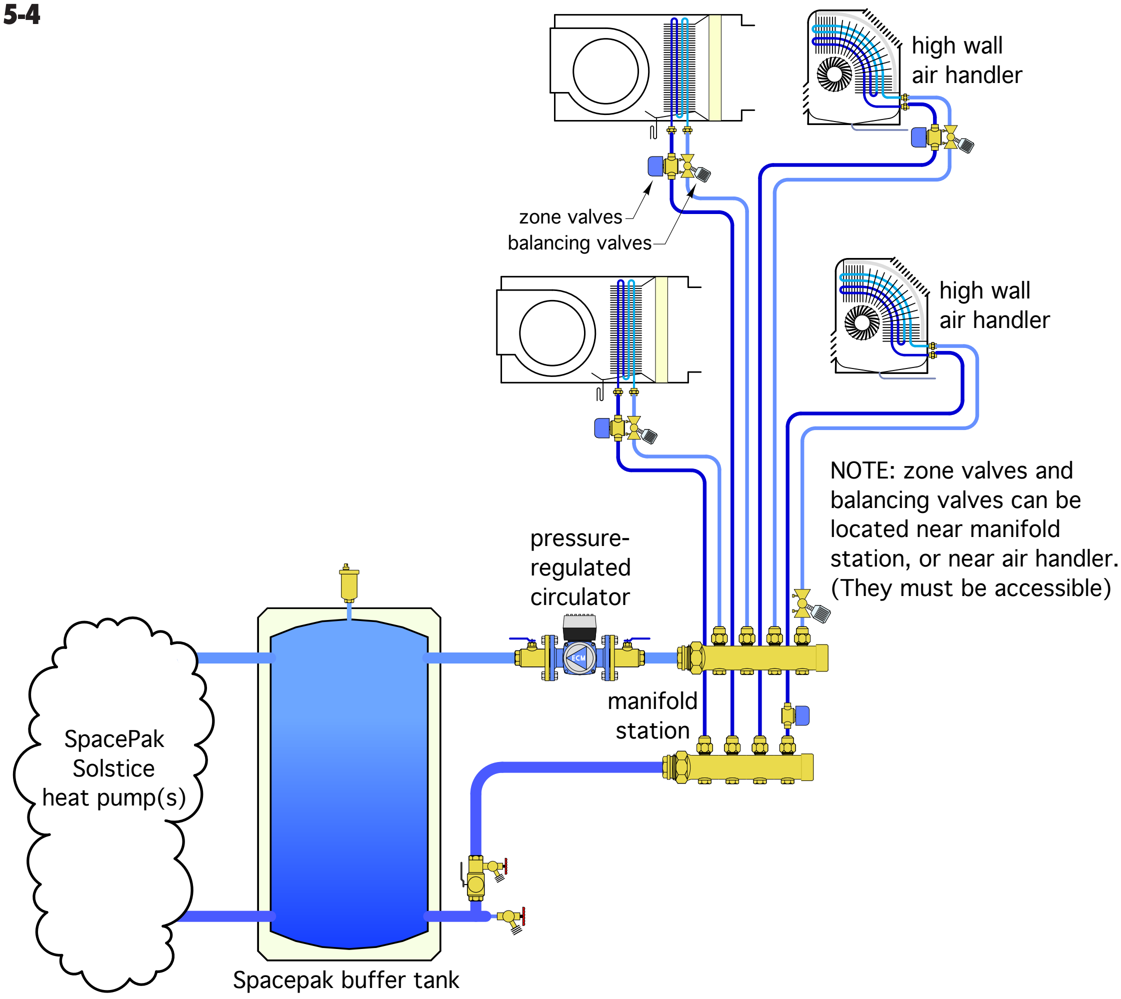


When a manifold valve actuator is unpowered, it holds the manifold circuit valve to which it's attached in the closed position. When 24VAC power is applied to the actuator, typically through a thermostat circuit, the actuator retracts its stem, allowing the manifold valve to open. An end switch within the actuator closes when the valve is fully open. This switch closure can be used to signal the circulator to operate, and thus, provide flow through any manifold circuits that are open. It allows any type of low-voltage thermostat to control heat input to each zone.

It's also possible use homerun distribution systems for chilled-water cooling applications. Figure 5-4 shows an example of four individually controlled chilled-water air handlers, such as SpacePak HighWall units or WCSP-J air handlers.

The buffer tank in Figure 5-4 only supplies chilled water. Therefore, it has been configured for best performance in cooling mode. The coolest water in the lower portion of the tank is supplied to the air handler. Slightly warmer cool water returning from the fan-coils goes into the upper portion of the tank.

Figure 5-4



Homerun distribution systems provide several advantages for both heating and cooling applications:

• When each homerun circuit contains a thermostatic radiator valve, or is supplied from a manifold station with valve actuators, each heat emitter can operate as an independently controlled zone. This allows the heat output of each heat emitter to adjust for internal heat gains that may occur in different rooms at different times, without affecting the comfort level in other rooms.

• Each heat emitter receives the same supply water temperature. This allows the maximum possible heat output from the system for any given supply water temperature. It also simplifies heat emitter sizing, since the designer doesn't have to compensate for the temperature drop from one heat emitter to the next, as is the case in series distributions systems.

• It's possible to balance each circuit for proper flow rate using the valves built into the manifold station or the balancing hardware built into most thermostatic radiator valves.

• The parallel versus series arrangement of heat emitters produces less head loss in the distribution system. This translates into low circulator power requirements, and thus, reduced operating cost.

• Segments of 1/2" PEX or PEX-AL-PEX tubing that are leftover from radiant panel installations, but are too short for other radiant panel circuits, can sometimes be used for the supply or return tubing in a homerun distribution system.

6. USE OF BUFFER TANKS

Buffer tanks provide additional thermal mass between a hydronic heat source, such as an air-to-water heat pump, and a zoned distribution system. They allow the rate of heat production by the heat source to be very different from the rate of heat dissipation by the heat emitters. When the heat source is operating, the buffer tank absorbs the difference between the rate of heat production at the heat source and the rate of heat dissipation to the load. This allows the heat source to remain on for several minutes, and not "short cycle." Operating the heat source for longer on-cycles reduces wear on components such as compressors and relays, which increases the service life of the heat source.

Once the buffer tank has been heated to a specific temperature, the heat source turns off. Any heating load that is operating draws heated water from the upper portion of the buffer tank, and returns cooler water to the lower portion of the tank. This allows the heat source to remain off for a reasonable time and prevents short-cycling.

The use of buffer tanks is encouraged for most systems using Solstice SE or Solstice Extreme heat pumps.

Designers should consider the following factors when determining if a buffer tank is needed:

1. How extensively is the distribution system zoned?
2. What is the heating load of the smallest zone?
3. What is the thermal mass of the distribution system?
4. What is the minimum heating and cooling capacity of the heat pump?

When a buffer tank *must* be used:

Systems that are supplied by Solstice heat pumps, have more than one zone, and use low thermal mass heat emitters, such as fin-tube baseboard, panel radiators, fan-coils or non-slab radiant panels, must have buffer tanks.

The volume of the buffer tank can be calculated based on the desired "on-cycle" time of the heat pump, the temperature change in the buffer tank during that on-cycle, and the minimum load that is operating when the heat pump is on. Formula 6-1 takes these factors into account.

Formula 6-1:

$$V = \frac{t\left(Q_{HP} - Q_{min}\right)}{500\left(\Delta T\right)}$$

Where:
V = required minimum volume of the buffer tank (gallons)
Q_{HP} = the maximum anticipated heat output of the heat pump (Btu/hr)*
Q_{min} = the minimum heating load that would be operating for the heat pump to be on (Btu/hr)
t = the minimum "on-cycle" time for the heat pump (minutes)
ΔT = the change in average tank temperature from when the heat pump turns on to when it turns off (ºF)

** for 2-stage heat pumps such as the Solstice SE, Q_{HP} = the maximum output of a single stage (Btu/hr)*

Example: Determine the required size of a buffer tank for a heat pump that delivers 48,000 Btu/hr, when the minimum desired on-cycle time is 10 minutes, and the change in average tank temperature during this time is 15ºF. The minimum load that would be operating simultaneously with the heat pump is 4,000 Btu/hr.

Solution:

$$V = \frac{t\left(Q_{HP} - Q_{min}\right)}{500\left(\Delta T\right)} = \frac{10\left(48{,}000 - 4000\right)}{500\left(15\right)} = 58.7\,gallons$$

Discussion: A 60-gallon buffer tank would work well in this situation.

Notice that the volume of the buffer tank is directly proportional to the desired "on-time" of the heat pump, and inversely proportional to the change in average tank temperature. Doubling the desired on-time would double the required volume of the buffer tank. Cutting the allowed temperature change in half would also double the volume of the tank.

For most heat pumps, the change in average tank temperature should not exceed 20ºF. This keeps variation in the heat pump's heating capacity and COP reasonable. It also keeps the change in water temperature supplied to the load from the tank reasonable.

SpacePak currently offers buffer tanks with 26-, 40- and 80-gallon volumes. The 40-gallon tank is shown in Figure 6-1. Multiple 80-gallon tanks can be combined in parallel when greater storage volumes are needed. Piping for multiple buffer tanks is discussed later in this section.

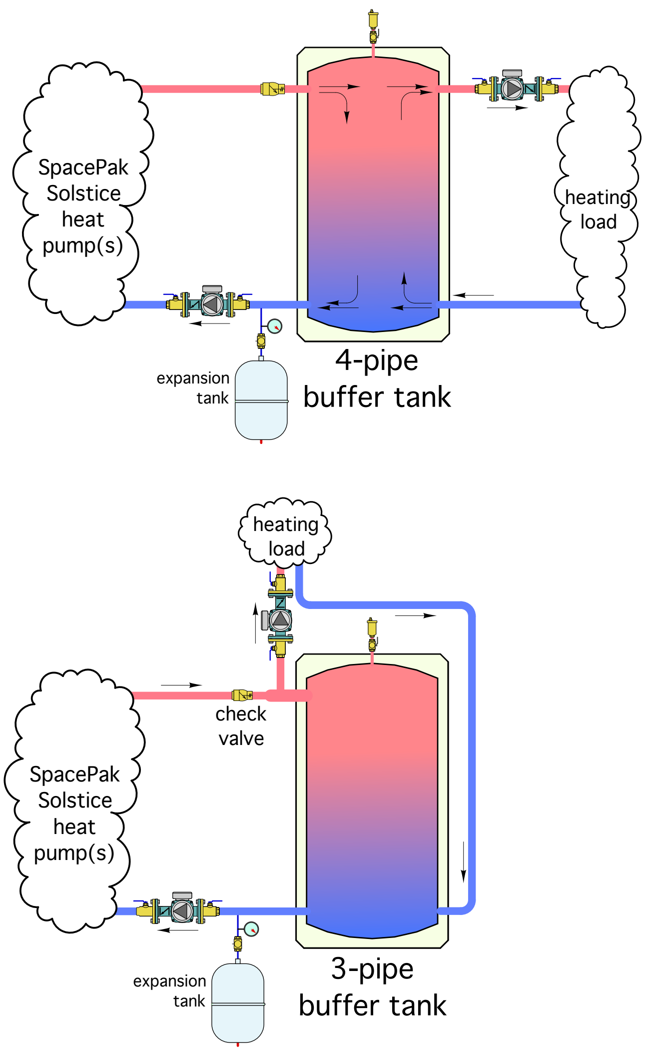
Buffer tank configuration:

Buffer tanks should be piped in ways that preserve temperature stratification (e.g., hottest water at top and coolest water at bottom). A well-stratified thermal storage tank preserves the *usefulness* of the thermal energy contained in the tank.

Temperature stratification can be destroyed by vertical flow jets within the tank. To avoid this, all piping that brings flow into the tank should enter horizontally. The flow velocity entering the tank should also be minimized. An entering flow velocity not exceeding 2 feet per second is suggested.

Figure 6-1

Figure 6-2



The two common ways of piping a buffer tank are shown in Figure 6-2.

The "4-pipe" buffer configuration is common in North America. The heat pump adds heat into the tank's upper sidewall connection. The load is supplied from another upper sidewall connection on the opposite side of the tank. Flow returns from the load to a lower sidewall connection. The heat pump receives flow from another lower sidewall connection.

Although the "4-pipe" configuration has been successfully used in many systems, it requires the thermal mass of the buffer tank to interact with energy flow from the heat pump to the load under _all_ conditions. If the buffer tank is at a low temperature when heat input begins, delivery of water to the load — at the same temperature supplied from the heat source — is delayed.

The "3-pipe" buffer configuration places the piping leading to the heating load *between* the heat pump and the buffer tank. If the load is operating at the same time as the heat pump, which is common, this piping configuration allows some (or all) of the flow from the heat source to go directly to the load. This speeds heat delivery to the load during critical times such as recovering from a temperature setback or following a "cold start" of the system.

Water returning from the load enters the lower portion of the buffer tank, and thus, a portion of the cooler thermal mass in the tank will always be "active" between the heat pump and the load. This helps ensure longer operating cycles for the heat pump. This is especially important in systems with extensive zoning.

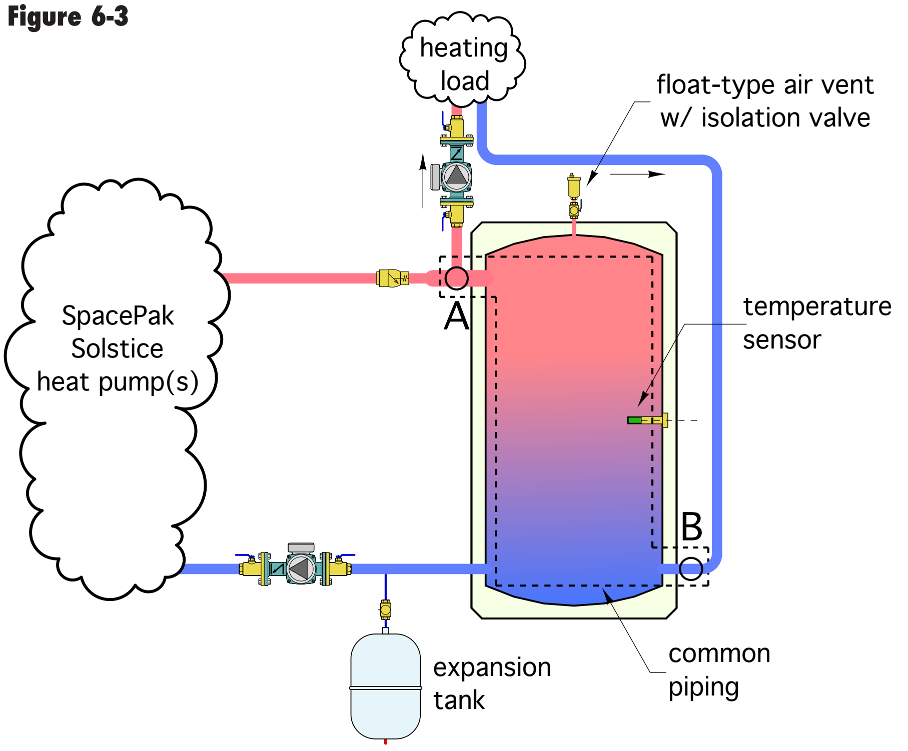
The flow rate passing through the buffer tank will be the *difference* between the heat pump flow rate and the load flow rate. For example, if the flow rate from the heat pump is 10 gpm, and the load flow rate is 7 gpm, the flow rate entering the upper sidewall connection of the tank is 10 – 7 = 3 gpm. The reduced entering flow rate, in comparison to what it would be in a 4-pipe tank configuration (e.g., 10 gpm), helps preserve temperature stratification within the tank.

For these reasons, the "3-pipe" buffer tank configuration has an advantage relative to the "4-pipe" configuration. Several of the system templates presented later in this manual will feature a 3-pipe buffer tank configuration.

3-pipe buffer tank details:

There are several piping details that allow a 3-pipe buffer tank to perform optimally. They are shown in Figure 6-3, and described as follows:

Figure 6-3



1. The load piping should tee into the tank piping *as close to the tank as possible* (e.g., points A and B in Figure 6-3 should be *located as close to the tank as possible)*. This minimizes the head loss of the flow path through the "common piping" shared by the heat pump circuit and the load circuit. Keeping the head loss of the common piping as low as possible allows the thermal storage tank to provide hydraulic separation between the heat pump circulator and the load circulator, which prevents them from interfering with each other.

2. A check valve should be installed upstream of where the load supply piping tees into the upper tank header. This valve ensures that a reverse thermosiphon will not develop when the buffer tank is warm, but the heat source is off. This helps reduce standby heat loss from the tank. It is also possible to use a motorized ball valve in place of the check valve. The motorized ball valve only opens when the heat pump circulator is on.

3. The sidewall piping connections to the tank should be generously sized. A suggested criterion is to keep the flow velocity entering the tank at or below 2 feet per second. This may require the short headers connected to the sidewall connections of the tank to be of larger diameter piping.

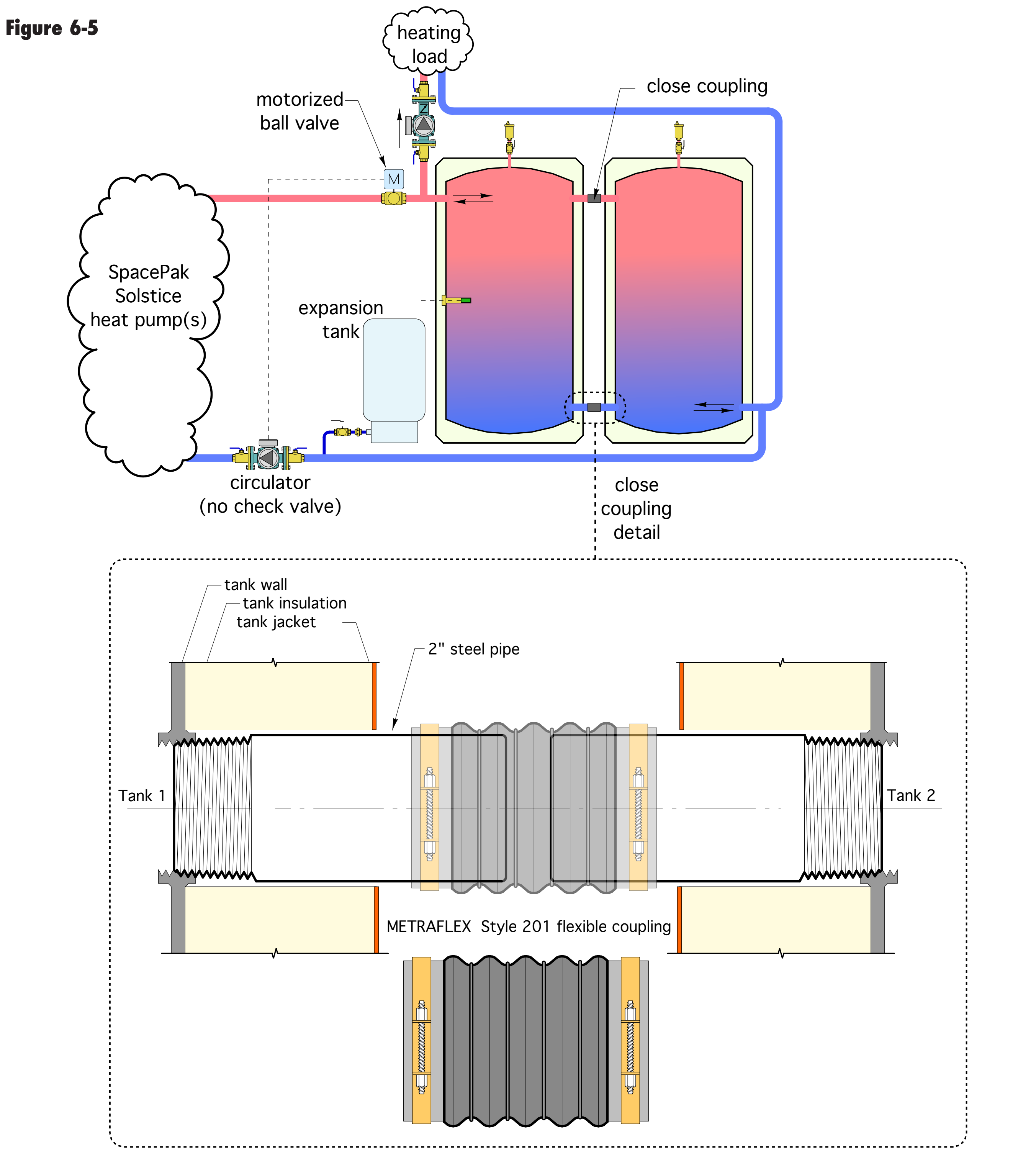
4. Install a float-type air vent at the top of the buffer tank to allow internal air to escape as the tank is filled above the upper sidewall connections. Mount this vent atop an isolation valve that can be closed if the vent ever needs servicing or replacing.

5. The upper and lower side wall connections should be as close as possible to the top and bottom of the tank shell. This ensures that all the water volume in the tank participates in the energy exchange process.

6. The heat pump is turned on and off based on the temperature at a sensor located on the tank. That sensor

Figure 6-4

Figure 6-5

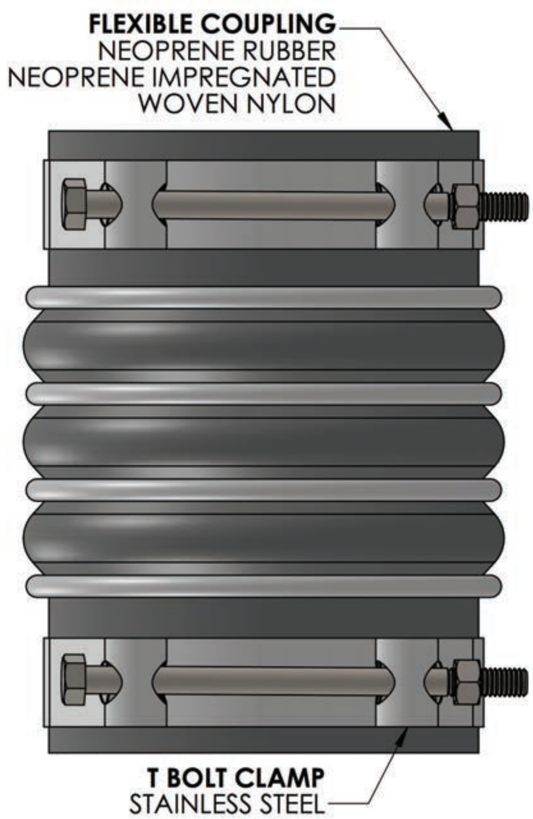


heating load
motorized ball valve
close coupling
M
SpacePak Solstice heat pump(s)
expansion tank
circulator (no check valve)
close coupling detail
tank wall
tank insulation
tank jacket
2" steel pipe
Tank 1
Tank 2
METRAFLEX Style 201 flexible coupling

should be mounted into an immersion well. The sensor should fit snugly inside the well, and be fully coated with thermal grease prior to being inserted. It should be pushed all the way into the well and fixed in a way that prevents it from being accidentally pulled toward the open end of the well. Figure 6-4 shows an example of a 3/4" MPT threaded immersion well that can be threaded into a mid-height connection on a buffer tank.

7. The expansion tank must be sized to accommodate the total fluid volume of the tank and other piping in the system. It should be connected to the system relatively close to the bottom of the buffer tank, which places it, *from the standpoint of dynamic pressure drop*, close to the inlets of the heat source circulator as well as the circulator carrying heat to the load.

Figure 6-6



Courtesy of Metraflex

Multiple buffer tanks:

When large buffer tank volumes are required, multiple tanks can be connected to create a hybrid configuration, as shown in Figure 6-5.

The side connections between the tanks should have minimal pressure drop. One possibility is using a short flexible coupler between the tanks, as shown in Figure 6-5. Flexible couplings are available for direct clamping to pipe sizes down to 2-inch. Figure 6-6 shows one example.

Multiple buffer tanks usually create a higher surface area-to-volume ratio compared to a single tank with the same volume. To minimize standby heat loss, the buffer tanks and piping connecting the tanks should be well insulated. Tanks used for relatively low-temperature heat storage, such as in systems using Solstice air-to-water heat pumps, should have a minimum insulation R-value of 12ºF•ft^2•hr/Btu. Tanks used in systems with higher-temperature heat storage should have even higher insulation R-values.

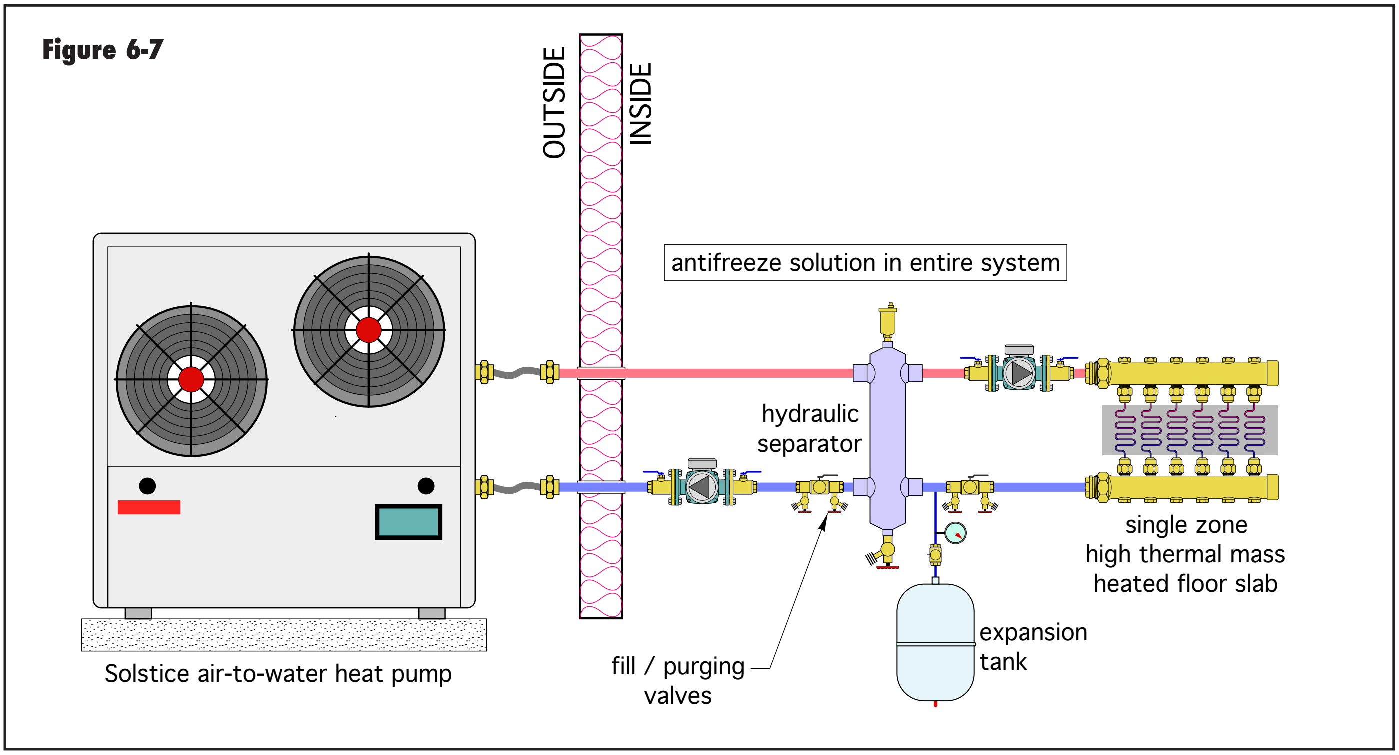
Figure 6-5 also shows a motorized ball valve in the piping leading from the heat pump to the buffer tank. This valve, if present, closes whenever the heat pump circulator is off, and opens when it is on. When closed it prevents any thermal migration from the buffer tanks though the heat pump. This reduces heat loss.

When a buffer tank is not needed:

Most systems using Solstice heat pumps will have more than one heating or cooling zone, and may have heat emitters or cooling terminal units with relatively low thermal mass. <u>*Because of this, it's imperative to use a buffer tank between the heat pump(s) and the load circuits.*</u>

However, if the system has ***<u>ALL</u>*** of the following characteristics, it's possible to eliminate the buffer tank:

1. The system is a single zone.
2. The design heating load matches or exceeds the design heating capacity of the heat pump.
3. The distribution system is a high thermal mass heated floor slab.



Heated floor slabs have very high thermal mass. For example, the thermal mass of a 24-foot by 40-foot concrete slab that's 4" thick is 9314 Btu/ºF. By comparison, the thermal mass of an 80-gallon buffer tank is 666 Btu/ºF. The slab's thermal mass is about 14 times greater than the 80-gallon buffer tank. This implies that a 1ºF change in the average slab temperature would be equivalent to a 14ºF change in the buffer tank temperature.

The large thermal mass of the heat floor slab heat emitter, in combination with proper water temperature controls, provides sufficient buffering to protect an air-to-water heat pump against short cycling. The heat pump's internal controller must be set to provide an adequate differential between the temperature at which the heat pump turns on and off.

A basic arrangement for a heating-only, single zone high-mass concrete slab heated by a Solstice heat pump without a buffer tank is shown in Figure 6-7.

The hydraulic separator in Figure 6-7 allows the flow rates between the heat pump and manifold station serving the floor-heating circuits to be different. It also prevents interference between the two circulators, captures and releases air from the system fluid, and captures dirt particles within the system.

7. FREEZE PROTECTION OPTIONS

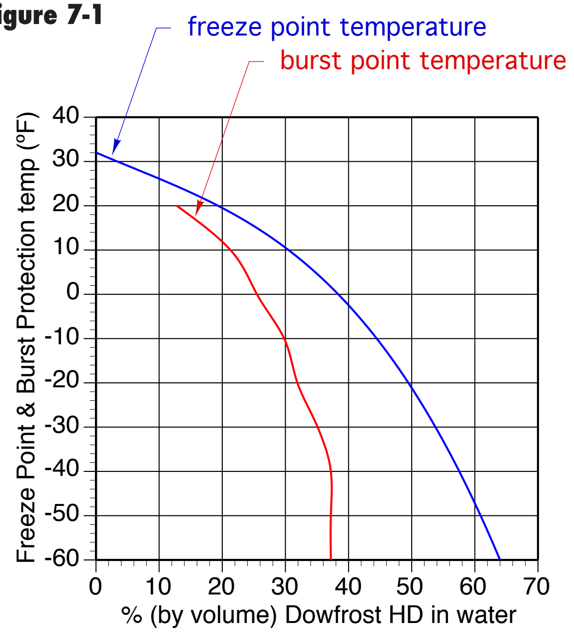
If water is allowed to freeze within any heat pump, the refrigerant-to-water heat exchanger could be ruptured.

SpacePak recommends that a non-toxic antifreeze solution be used in all systems using Solstice heat pumps. The required concentration of that solution can vary depending on the possible sub-freezing temperatures at the installation site and a requirement of the antifreeze solution to provide either "freeze protection" or "burst protection."

Freeze vs. burst protection:

The *freeze-point* temperature of an antifreeze solution is the minimum temperature at which the solution remains flowable. Small ice crystals are just beginning to form in the fluid when it drops to its freeze-point temperature. This temperature is well below the normal operating temperature of any Solstice heat pump. However, if it is possible that the heat pump may have to start after being off for several hours in very cold ambient conditions, the antifreeze solution used should have a freeze-point temperature as low as the minimum ambient air temperature at which the cold start could occur.

Figure 7-1



The *burst-point* temperature of an antifreeze solution is the lowest temperature at which the piping and piping components that contain the solution will not be subject to expansion forces that could rupture them. The antifreeze solution will be mostly ice crystals when it drops to burst point temperature, and thus, *not* flowable.

Figure 7-1 compares the freeze protection temperature and burst protection temperature for a range of volumetric concentrations of an inhibited propylene glycol antifreeze.

Based on Figure 7-1, a 35% solution of propylene glycol antifreeze remains flowable down to 5ºF, and protects the heat pump and piping against bursting down approximately -35ºF. A 50% solution of the same antifreeze remains flowable down to -20ºF, and provides burst protection to temperatures below -60ºF. The objective is to select a concentration that adequately protects the system, but doesn't use excessive amounts of antifreeze. The higher the antifreeze concentration, the higher the viscosity of the fluid, and the greater the flow resistance of the circuit. Adding antifreeze to water also decreases the heat transfer capacity of the solution. A 50% solution of propylene glycol antifreeze lowers the specific heat of the solution to approximately 90% that of water. This can be compensated by using higher flow rates, but that can significantly increase circulator power requirements.

Using antifreeze in the system:

There are several ways of using antifreeze in systems with Solstice heat pumps. The simplest method is to fill the entire system with the antifreeze solution, as shown in Figure 7-2.

This approach eliminates the need for a heat exchanger between the heat pump and the portion of the system that contains just water. This increases the heating capacity and COP of the heat pump relative to systems that use heat exchangers between the heat pump and the balance of the system. It also provides burst protection for the entire system, which could be very beneficial during a prolonged power failure or system breakdown during cold weather. In most residential systems, the cost of using an antifreeze solution throughout the system is less than installing a properly-sized heat exchanger, an extra circulator and related piping hardware.

Figure 7-2

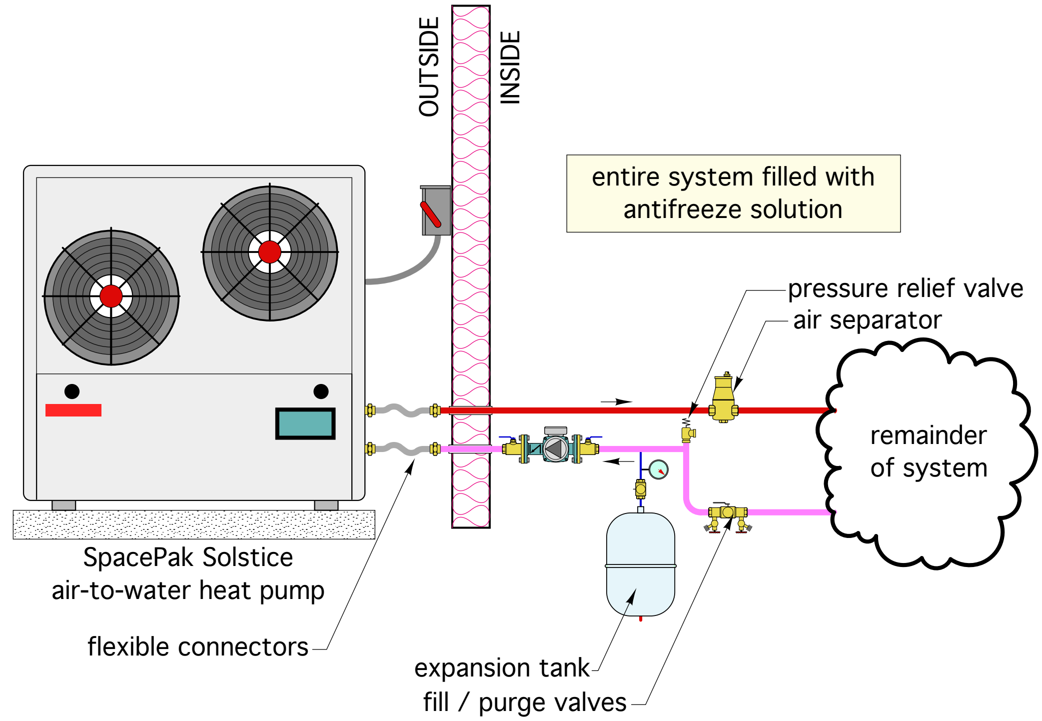
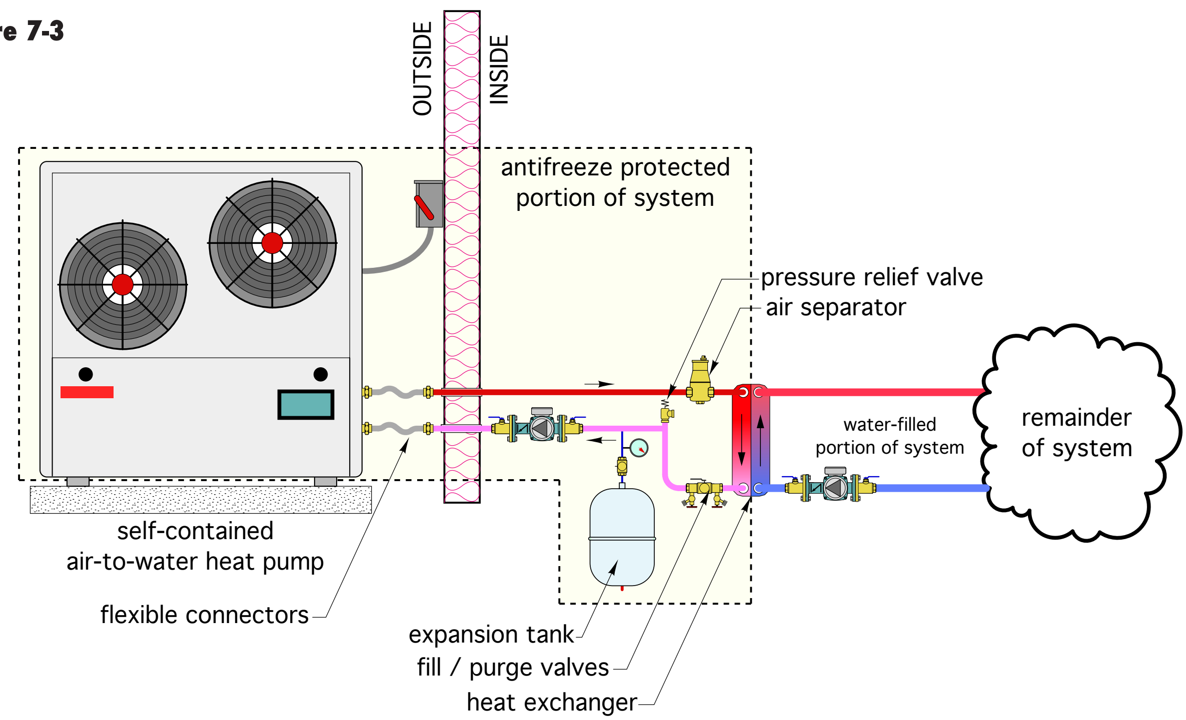


Figure 7-3

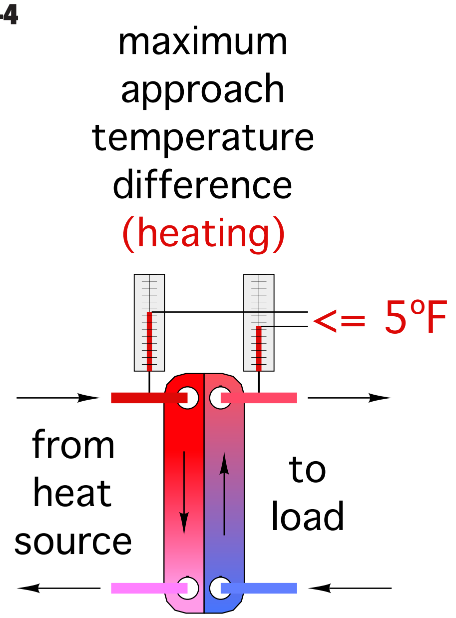


Another approach is to install a generously sized heat exchanger between the heat pump and the balance of system, as shown in Figure 7-3.

This approach only requires antifreeze in the circuit between the heat pump and heat exchanger. That portion of the system is a closed loop and is completely isolated from the balance of the system. As such, it requires a separate circulator, expansion tank, pressure-relief valve, air separator and fill/purging valves. A pressure gauge should also be installed to monitor the closed loop for any drop in pressure.

It's extremely important that the heat exchanger can transfer the maximum heating and cooling capacity of the heat pump while operating at an approach temperature difference no higher than 5ºF. Figure 7-4 illustrates the approach temperature difference for a heat exchanger.

Figure 7-4



The approach temperature difference is the temperature of the fluid supplied from the heat pump to the heat exchanger minus the temperature of the fluid leaving the other side of the heat exchanger. The "ideal" heat exchanger would have an approach temperature difference of 0. This would require a heat exchanger with an infinite surface area, which is obviously not possible. Still, designers should strive to select heat exchangers such that the approach temperature difference is as low as possible, and in the case of a heat pump system, never over 5ºF.

Designers can select appropriate heat exchangers using online software from heat exchanger manufacturers. These heat exchangers should be selected based on the design load fluid temperatures and flow rates.

Figure 7-5 shows examples of two flat-plate stainless steel heat exchangers.

Figure 7-5

The smaller heat exchanger in Figure 7-5 has 40 5" x 12" stainless steel plates. The larger heat exchanger has 100 5" x 12" stainless steel plates. Of these, the larger heat exchanger can transfer 60,000 Btu/hr with an approach temperature difference of less than 5ºF, and thus, would be compatible with either of the Solstice heat pumps when piped as shown in Figure 7-3. Brazed-plate stainless steel heat exchangers like those shown are available from several North American suppliers.

Using a heat exchanger between the heat pump and balance of system forces the heat pump to operate at temperatures slightly higher than those required in systems where no heat exchangers are used (during heating mode), and slightly colder in cooling mode. If the heat exchanger is sized based on the above recommendation, the heat pump should operate about 5ºF higher that the water temperature delivered from the heat exchanger in heat mode operation. This will slightly reduce heat capacity and COP relative to a system without a heat exchanger.

Heat exchangers that isolate the heat pump from the balance of the system are appropriate in systems with large fluid volumes that would otherwise be filled with just water. Examples include systems with extensive radiant panel circuits and/or large buffer or thermal storage tanks. In other systems, it is simpler, more efficient and likely less expensive to use an antifreeze solution throughout the system.

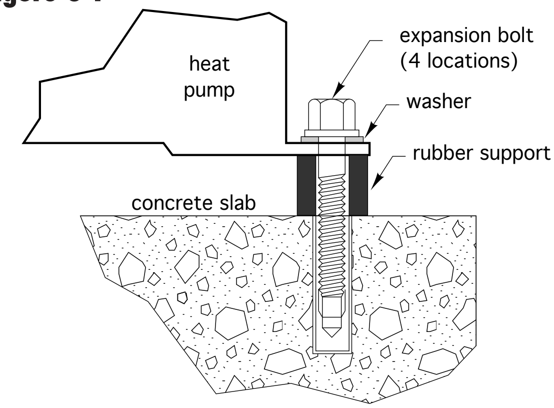
8. HEAT PUMP PLACEMENT AND EXTERNAL PIPING DETAILS

Solstice heat pumps require piping between the exterior unit and the interior portion of the system. The type of piping used depends on how the heat pump is mounted and the distance between it and the building it serves.

All solstice heat pumps must be mounted on a stable foundation that's high enough to prevent snow, ice or lawn debris from accumulating against the unit.

In climates with minimal snow, the heat pump can be supported on a small concrete slab that elevates the unit several inches above the ground. The slab should be dimensioned large enough to accommodate expansion bolts at all four fastening points. There should be a minimum of 3 inches of concrete between the expansion bolts and the edge of the slab. Solstice heat pumps are supplied with rubber vibration isolators that should be installed between the bottom of the anchor tabs and the foundation, as shown in Figure 8-1.

Figure 8-1



In climates with significant snow accumulation, the heat pump should be mounted on an elevated base that's high enough to prevent snow from accumulating against the unit. Figure 8-2 shows one such base that was fabricated from pressure-treated lumber and supported by a pressure treated 6x6 post that rests on a small concrete pad located about 4 feet below final grade. This depth prevents movement of the post due to frost.

Figure 8-2

The base frame is stabilized by two threaded steel rods that are attached to the building.

All foundations should maintain at least 20 inches of clear space between the rear of the heat pump and the adjacent building wall. This provides adequate air intake space for the air handling section of the heat pump. It also provides access space to ensure the air intake of the heat pump is free of leaves or other debris.

The heat pump's mounting location should also consider precipitation, prevailing winds and solar gains.

Although Solstice heat pumps are designed for exterior duty, they should not be mounted where rain runoff from adjacent roofs will fall directly on the unit. If such a location cannot be avoided, a gutter should be installed over the unit, as seen in Figure 8-2, to minimize roof runoff on the unit. *Never mount the heat pump where a snow slide from a metal roof would impact it.*

It's also best to mount the heat pump so that it is partially shielded from strong winds. If possible, orient the heat pump so that prevailing winds will pass across the unit in the same direction as the airflow created by the external fans.

In cold locations, the performance of the heat pump can be slightly enhanced by mounting it where it's exposed to the sun during winter and at least partially shaded during summer. Such details, where they can be accommodated, create a "micro-climate" around the heat pump that can slightly warm the air temperature passing through the heat pump's evaporator during winter and slightly reduce that air temperature during summer.

All heat pumps produce some operating sound. As such, they should be located away from sound-sensitive areas such as outdoor patios or sleeping areas.

Finally, be sure to provide adequate service access when selecting the location for the heat pump. Ensure adequate clearance for removal of any service panels, as well as access to refrigeration service ports and wiring. Avoid placing the unit where shrub growth will eventually contact the unit, block air flow or impede easy access to it.

Multiple Solstice heat pump placement:

When two or more Solstice heat pumps are mounted adjacent to each other, be sure that the air flow created by one heat pump does not interfere with the air flow of another heat pump. Also be sure that service clearance is provided for all heat pumps.

Figure 8-3

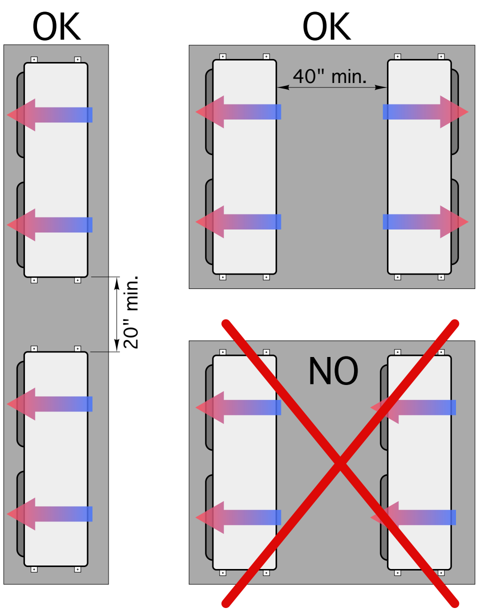


Figure 8-3 shows top views of typical mounting options for two adjacent Solstice heat pumps. Figure 8-4 shows parallel mounting of three Solstice SE heat pumps.

Figure 8-4

External piping details:

When a Solstice heat pump is mounted close to the building, flexible pressure-rated hoses, such as those seen in Figure 8-5a,b, can be used to transition between the heat pump piping connections and rigid piping within the building.

Figure 8-5a

Figure 8-5b

The piping penetrations through the building wall should be arranged so that flexible hoses will remain slightly bent. This allows the hoses to absorb slight movement without transferring significant stress or vibration to the rigid piping.

Figure 8-6

The rigid piping to which the hoses connect should pass through water-tight sleeves in the wall, as shown in Figure 8-6. PVC piping works well for sleeving, which prevents any condensation on the piping from leaking into the wall cavity. The outside of the sleeve can be wrapped with electrical tape where it passes through siding and sheathing to provide a tight friction fit.

After the piping to the heat pump is fully installed and pressure tested, the space between the rigid piping and the sleeve can be filled with an expanding foam insulation.

All external piping between the heat pump and wall must be insulated. An elastomeric foam insulation works well. A minimum 3/4" wall thickness is suggested. Once installed, this insulation should be wrapped with a UV-resistant tape or other coating to protect it from sunlight, insects and abrasion damage.

Remote mounting:

It's also possible to install one or more Solstice heat pumps a significant distance away from the building they serve, as seen in Figure 8-7.

Figure 8-7

In such cases, pre-insulated underground PEX piping, such as shown in Figure 8-8, should be installed between the heat pump location and the building.

Figure 8-8

Courtesy of Rovanco

The piping should be sized to allow adequate flow through the heat pump without excessive circulator power input. The suggested minimum pipe size is 1-inch. Larger pipe sizes such as 1.25" and 1.5", although more expensive than 1" pipe, will significantly reduce the size of the circulator and its operating cost over the life of the system.

The transition between the underground PEX tubing and the heat pump connections must be done in a manner that accommodates (or prevents) the thermal expansion movement of the PEX tubing. PEX tubing expands and contracts approximately 10 times more than metal piping for a given temperate change. This movement should be accommodated or prevented so that no significant stress is placed on the heat pump piping connections or adjacent rigid piping. One possibility is to use a metal transition fitting between the PEX tubing and a flexible pressure-rated hose, the latter connecting to the heat pump. The transition fitting should be tightly clamped to a steel structural element embedded in the concrete base, which serves as an anchor point. This anchor point prevents the stresses induced by temperature change in the PEX tubing from being transferred to the flexible hoses that connect to the heat pump.

9. FLOW CONSIDERATIONS

All heat pumps require adequate flow of both air and water (or water-based antifreeze solution) to maintain stable operation.

A guideline is to provide 2 to 3 gallons per minute (gpm) of water (or antifreeze solution) flow through the condenser of a heat pump *per ton* (e.g., 12,000 Btu/hr) of heating capacity. Flow rates below 2 gpm/ton can reduce heat transfer and lower the COP of the heat pump. Flow rate over 3 gpm/ton significantly increases circulator input power with minimal thermal performance gain from the heat pump.

The table in Figure 9-1 indicates the expected temperature rise across the heat pump's condenser based on the fluid and the flow rate.

Achieving adequate flow through a Solstice heat pump requires proper circulator selection. That, in turn, requires that the head loss of the heat pump and its circuit be determined.

The head loss due to friction of the fluid flowing through three models of Solstice heat pumps is shown in Figure 9-2.

The horizontal range of the head loss curve for each heat pump in Figure 9-2 gives the suggested flow rate range for that heat pump. For example, the Solstice Extreme heat pump is shown as the green curve, with a flow rate range of 8 to 14 gallons per minute.

In addition to the head loss of the heat pump, designers need to consider the head loss of the other components within the hydronic circuit of the heat pump. The head loss of that circuit's piping, fittings, valves, air separator and heat exchanger (if present) need to be added to the head loss of the heat pump to establish the total head loss of the circuit as a function of flow rate.

Figure 9-2

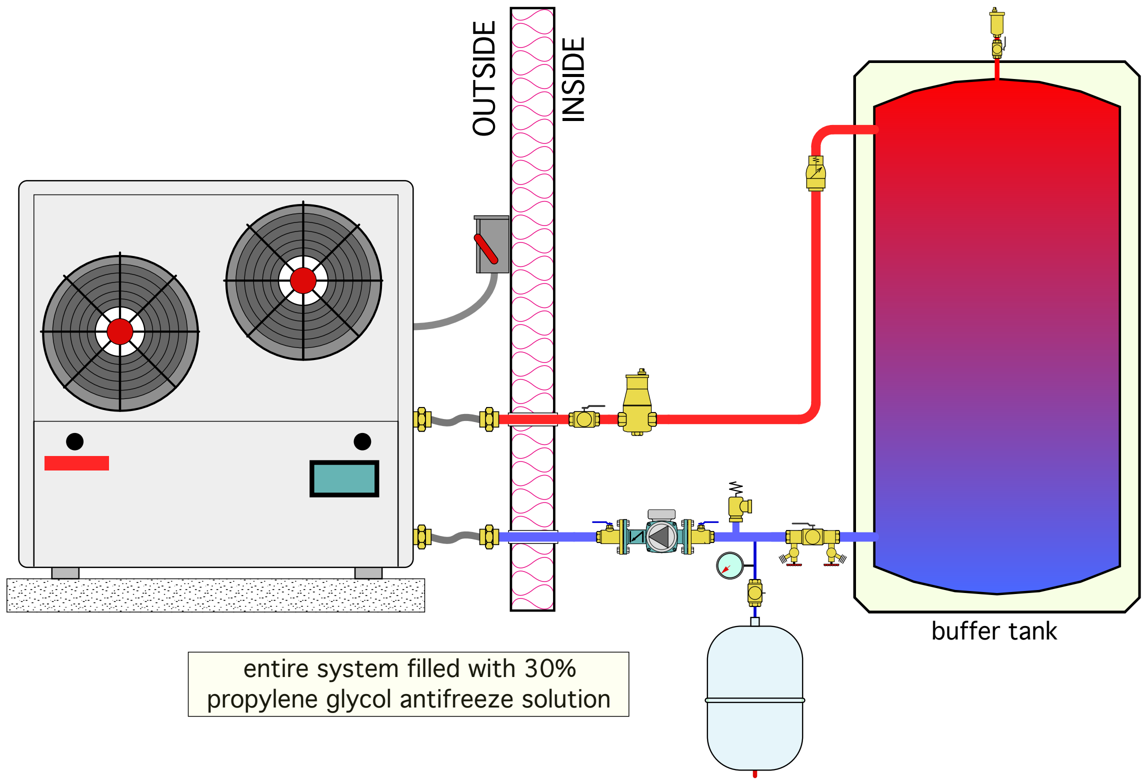
For example: Assume that the Solstice Extreme heat pump will be used in a circuit containing 25 feet of 1" type M copper tubing, as well as twelve 90º x 1" elbows, and three standard port ball valves. That circuit also includes an 80-gallon buffer tank and micro-bubble air separator. The entire circuit operates with a 30% solution of propylene glycol antifreeze with a typical fluid temperature in the range of 110ºF. Figure 9-3 shows an example of the circuit.

Reference 1 in Appendix C can be used to determine the head loss of the piping and components based on the concept of equivalent length. The equivalent length of the twelve 90º x 1"

Figure 9-1

water only (2 gpm/ton flow rate)	30% propylene glycol (2 gpm/ton flow rate)	water only (3 gpm/ton flow rate)	30% propylene glycol (3 gpm/ton flow rate)
12 °F	12.6 °F	8 °F	8.4 °F

Figure 9-3



elbows is 12 x 2.5 feet/elbow = 30 feet. The equivalent length of the three 1" standard port ball valves is 3 x 4.3 feet = 12.9 feet. The estimated equivalent length of the 1" air separator is 6 feet. The head loss created by flow through the buffer tank is extremely low and will be estimated with an equivalent length of 1 feet of 1" copper tube.

The *total* equivalent length of the piping, fittings, valves and other components (other than the heat pump) is therefore: 25 + 30 + 12.9 + 6 + 1 = 74.9 feet.

Using Reference 1 in Appendix C, the head loss of 74.9 feet of 1" type M copper tubing can be written as:

Formula 9-1:

$$H_L = (acL) f^{1.75}$$

Where:

a = fluid properties factor for 30% propylene glycol at an average temperature of 110ºF (a = 0.062)

c = pipe size coefficient for 1" type M copper tube (c = 0.01776)

L = total equivalent length of circuit = 74.9 feet

f = flow rate (gpm)

1.75 = an exponent of flow rate.

Putting these values into Formula 9-1 yields:

$$H_L = (acL) f^{1.75} = (0.062 \times 0.01776 \times 74.9) f^{1.75} = (0.0824) f^{1.75}$$

This equation can be plotted on a graph along with the head loss curve for the Solstice Extreme heat pump as shown in Figure 9-4.

Figure 9-4

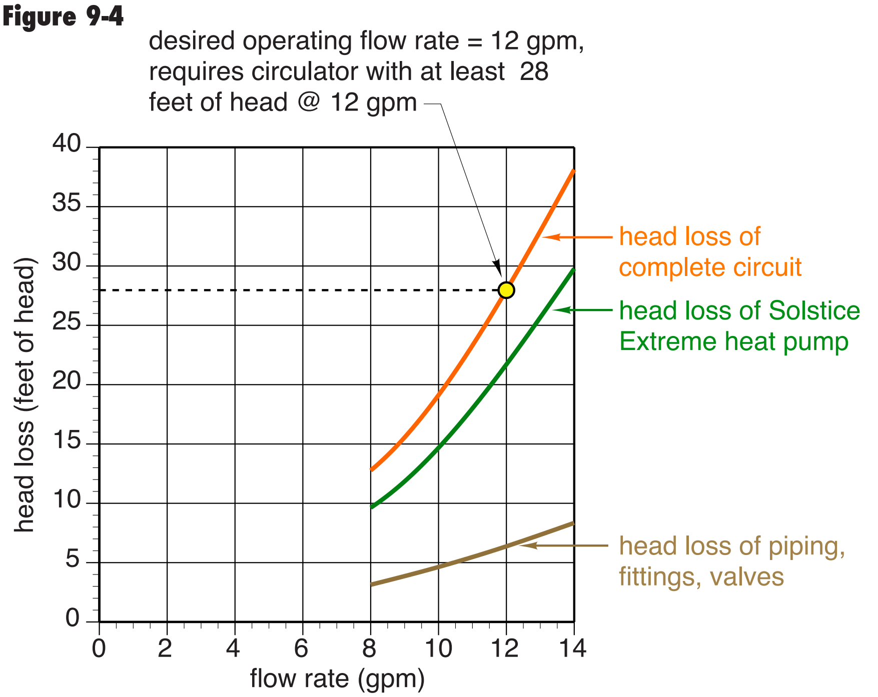
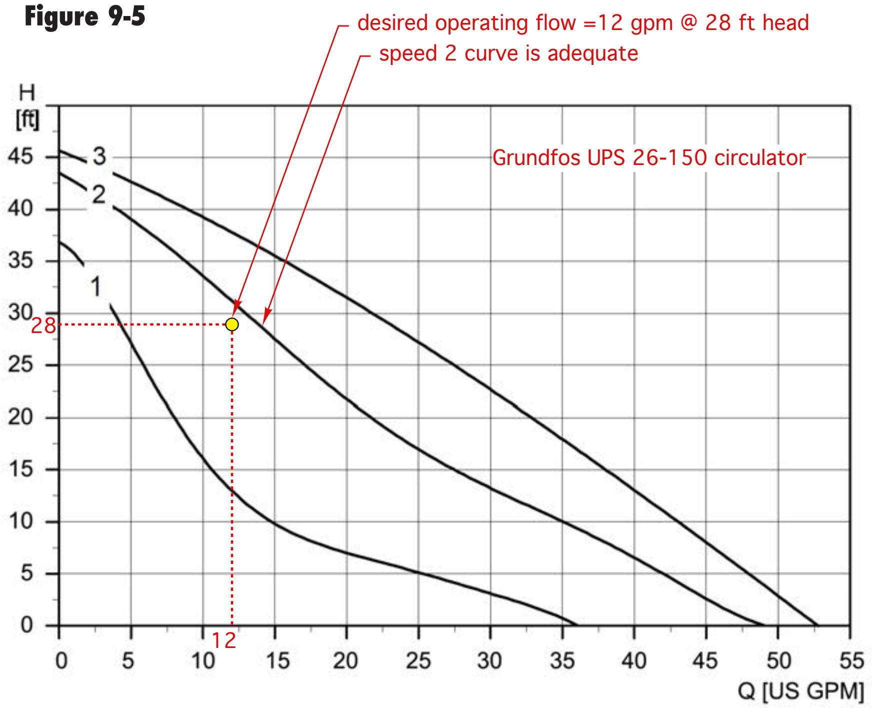


Figure 9-5



The upper (orange) curve represents the *total* head loss of the heat pump circuit, including the heat pump, piping, fittings, valves, buffer tank and air separator.

A circulator can now be selected based on the desired flow rate through the heat pump, and the corresponding head loss of the heat pump's circuit.

Assume that the designer wants a flow rate of 12 gpm through the Solstice Extreme heat pump. The corresponding head loss can be read from the upper (orange) curve in Figure 9-4 as 28 feet. The designer can now search for a circulator that can produce at least 28 feet of head while operating at a flow rate of 12 gpm.

Figure 9-5 shows a set of pump curves for a specific circulator. The yellow dot on this graph indicates the chosen operating condition (e.g., flow rate = 12 gpm, with corresponding head loss of 28 feet). The speed 2 curve of this circulator passes just above this operating point, making this circulator a possible selection to achieve the necessary operating conditions of the heat pump circuit.

10. BASIC ELECTRICAL CONNECTIONS

Solstice heat pumps require two types of electrical wiring between the heat pump and the balance of system: Low-voltage wiring and line voltage wiring.

Low-voltage wiring determines when the heat pump operates, as well as the mode of operation (e.g., heating or cooling).

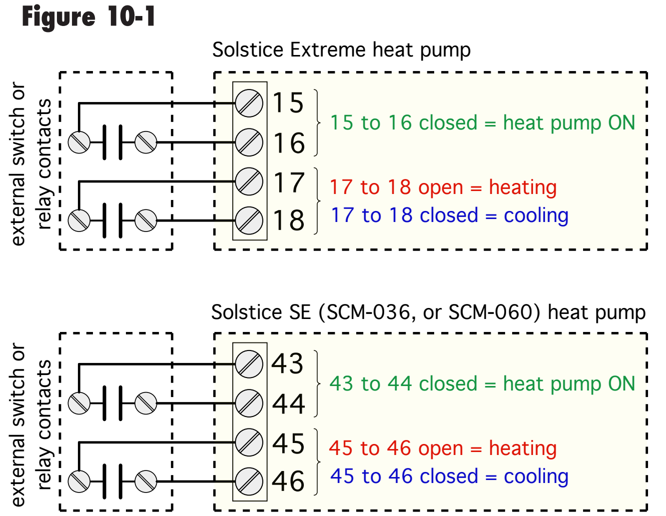
Line voltage wiring supplies power to operate the heat pump's compressor and other line voltage components contained within, or controlled from the heat pump.

Designers should always verify that their control system connects to the appropriate electrical terminals within the heat pump. Consult the latest Installation and Operating manual for a specific Solstice heat pump to ensure correct wiring. Designers must also ensure that all wiring meets the requirements of the latest edition of the National Electrical Code (ANSI/NFPA 70).

Low-voltage wiring:

The low-voltage electrical terminals within the Solstice SE and Solstice Extreme heat pumps are slightly different. Both are shown in Figure 10-1. *Always check the latest Installation and Operating manual supplied with the Solstice heat pump to verify electrical terminal numbering.*

Figure 10-1



An external switch or relay contact is necessary to turn the heat pump on. Another external switch or relay contact determines whether the heat pump operates in heating or cooling mode. These external contacts are called "dry contacts." They do not supply any electrical power to the heat pump. In most cases, they can be wired with 18 AWG copper wire.

Line voltage wiring:

The line voltage terminal strips in the Solstice SE and Solstice Extreme heat pumps also vary slightly, and are shown in Figure 10-2.

Figure 10-2

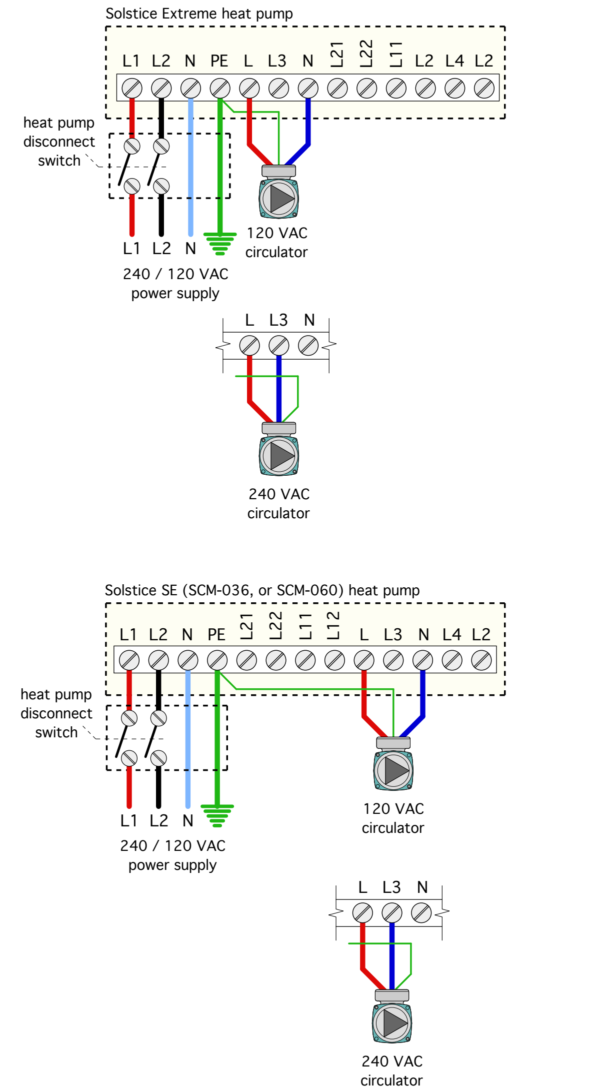
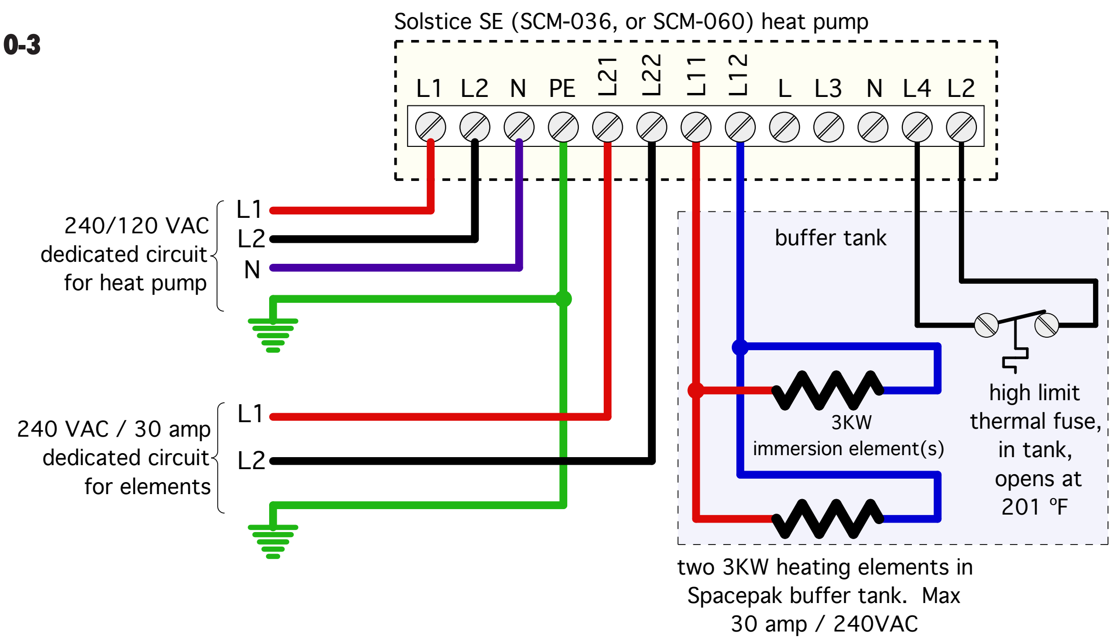


Figure 10-3



Power to operate the heat pump is supplied from a 240/120 VAC dedicated circuit with an ampacity as specified in the Solstice installation manual.

Terminals are provided to power the circulator that creates flow through the heat pump. These terminals are limited to 2.5 amps current demand. Both 120 VAC and 240 VAC circulators can be accommodated based on the terminals used.

Additional line voltage terminals are provided on the Solstice SE heat pump to operate one or two *optional* electric immersion heating elements in the system (typically contained within the SpacePak buffer tank). Figure 10-3 shows the wiring needed for this option.

Note that power to operate the electric heating element(s) must be provided by a separate dedicated 240 VAC circuit, 30 amp maximum ampacity.

11. SYSTEM TEMPLATES:

This section combines the many details presented in early sections of the manual into several complete system "templates" that have been developed for the Solstice SE and Solstice Extreme heat pumps. Each template includes a summary description, piping schematic, electrical schematic, a description of operation, and in some cases, suggested controller settings.

The templates range from simple "heating only" systems to more complex systems that provide heating, cooling and domestic hot water. Some systems also include a boiler as a supplemental heat source to the heat pump.

These templates are generic, and intended to serve as "starting points" for a final system design. Other than the heat pumps, they do not specify the exact hardware to be used to complete the design. The templates also may not represent the exact configuration required based on specific code requirements. Designers are responsible for adapting the templates presented to such requirements, and to select appropriate hardware, such as piping materials and sizes, circulators, expansion tanks and heat emitters, that allow the system to meet the capacity requirements of the building it serves and meet all applicable code requirements.

All the symbols used in the piping templates are listed in Appendix A. All the symbols used in the electrical templates are listed in Appendix B.

Template Summaries:

System #1: Solstice Extreme supplying a heating-only, single zone, high thermal-mass, low-temperature radiant floor heating distribution system.

System #2: Solstice Extreme supplying a heating-only, multiple-zone, low water-temperature, fin-tube baseboard distribution system.

System #3: Solstice Extreme supplying heating-only, multiple-zone panel radiators with room temperature regulated by thermostatic radiator valves.

System #4: Solstice SE heat pump supplying space heating using zoned low-temperature radiant panels, as well as domestic water preheating.

System #5: Solstice Extreme supplying multiple zones of low-temperature radiant panel heating and domestic water preheating using reverse indirect tank.

System #6: Solstice Extreme supplying multiple zones of low-temperature radiant panel heating and chilled-water cooling using zoned air handlers. Single buffer tank configuration.

System #7: Solstice Extreme supplying multiple zones of low-temperature radiant panel heating and chilled-water cooling using zoned air handlers. System also supplies prioritized domestic water preheating. Dual buffer tank configuration.

System #8: Solstice Extreme supplying multiple zones of low-temperature radiant panel heating, chilled-water cooling via air handlers, and domestic hot water. System includes auxiliary modulating/condensing boiler to supplement heat pump. Dual buffer tank configuration.

System #9: Two Solstice Extreme heat pumps in staged configuration supplying low-temperature radiant panel heating and chilled-water cooling using air handlers. Single buffer tank configuration.

System #10: Solstice Extreme heat pump supplies heating and cooling through five WCSP-J air handlers. System operation is managed by a SpacePak SSIC controller. Buffer tank can be "online" or bypassed based on load requirements.

SYSTEM #1:

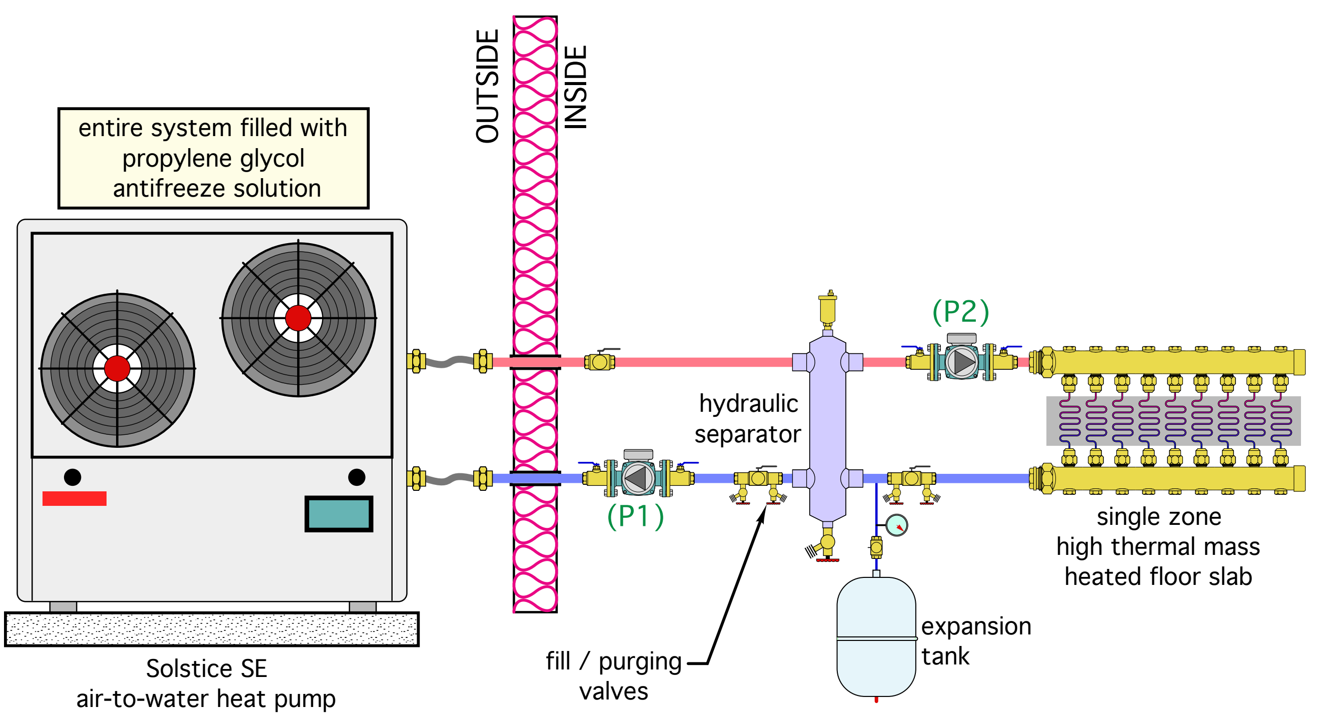
DESCRIPTION: This is a *single zone* heating-only system in which a Solstice SE 060 heat pump supplies heat to a high-mass/low-temperature radiant floor slab. The entire system is filled with a 30% inhibited propylene glycol antifreeze solution. The slab has been designed to dissipate the full output of the heat pump at a supply water temperature of 105ºF. The hydraulic separator allows for different flow rates between the heat pump circuit and the distribution system. It also provides air and dirt separation for the system. The high thermal-mass slab is "self-buffering," and thus, no buffer tank is needed.

Description of operation:

Power supply: The Solstice SE heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power to the heat pump. The remainder of the system is powered by 120 VAC / 15 amp circuit. The main switch (MS) must be closed to provide power to the control system.

Heating mode: 24 VAC is available to the heating thermostat (T1) whenever the main switch (MS) is closed. When thermostat (T1) calls for heat, 24 VAC is passed to relay coil (R1). Relay contact (R1-1) closes to pass 120 VAC to circulator (P2). Relay contact (R1-2) closes between terminals 43 and 44 on the

PIPING SCHEMATIC:



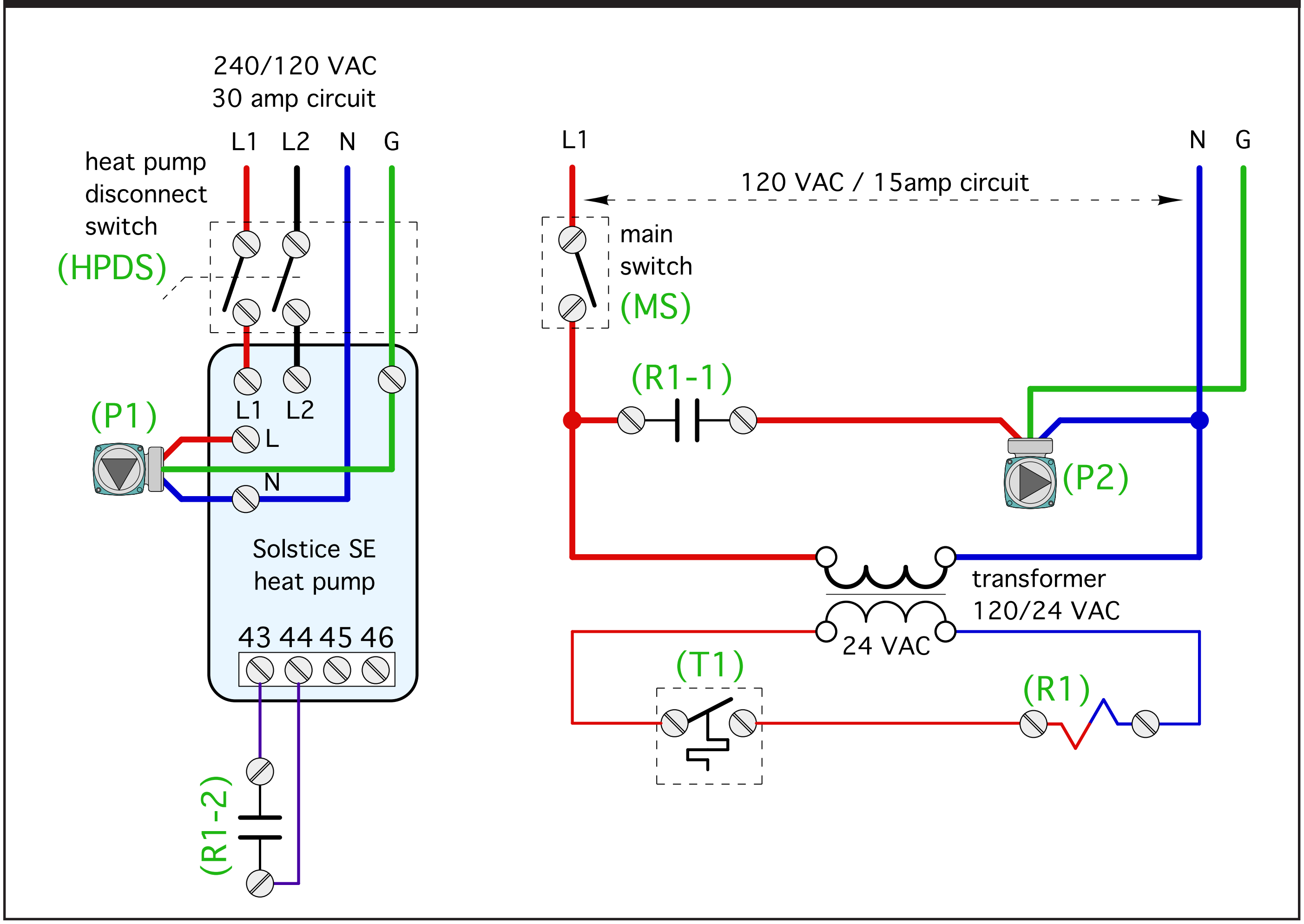
Solstice SE heat pump, enabling it to operate in heating mode. The heat pump circulator (P1) turns on within a few seconds of the heat pump being enabled to operate. An internal flow switch within the heat pump measures the flow rate through the heat pump. If sufficient flow is verified, the compressor starts. The heat pump continues to operate until thermostat (T1) is no longer calling for heat, or the heat pump reaches an internal upper temperature limit.

POSSIBLE HEAT PUMP SETTINGS:

Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 120ºF

Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 110ºF

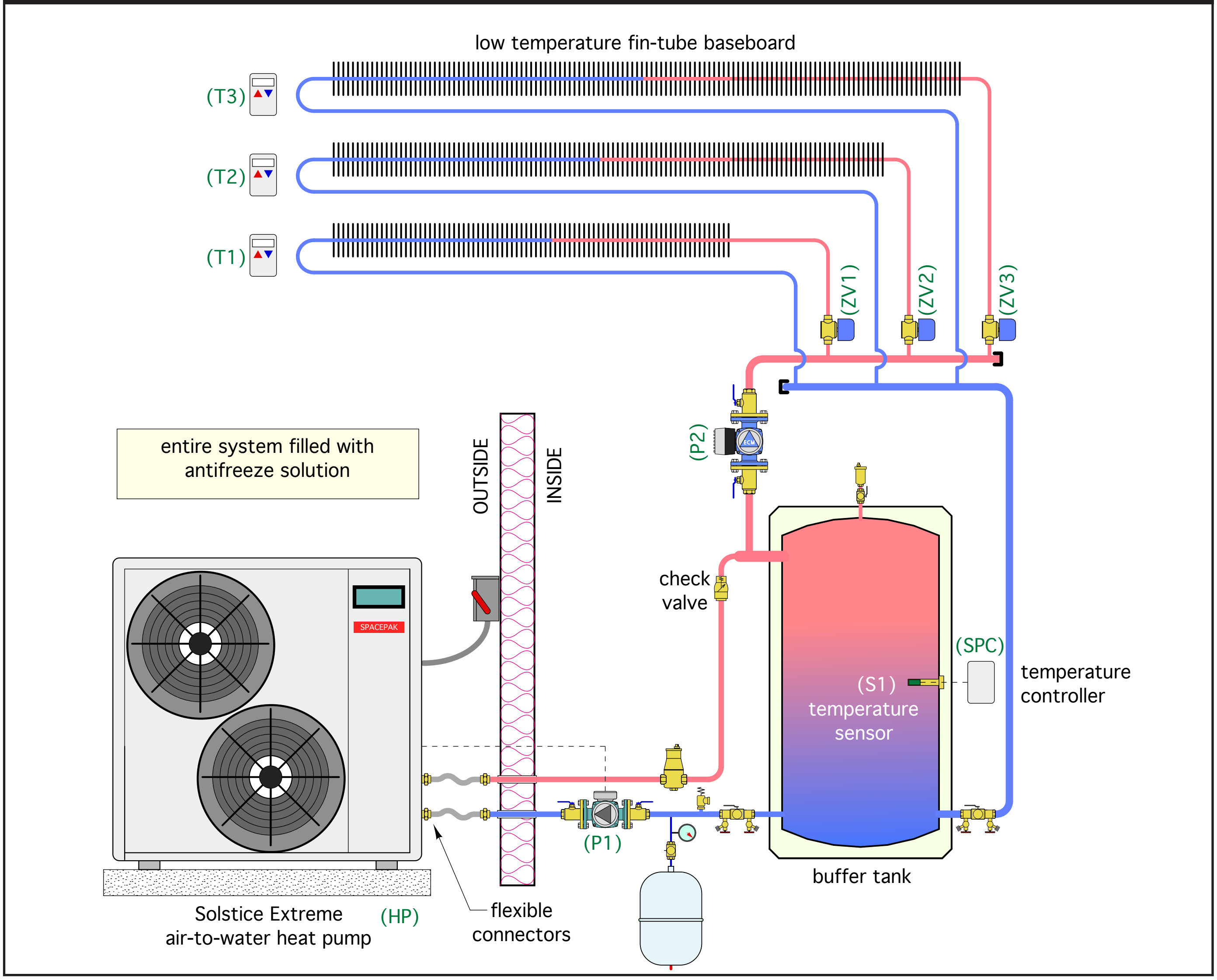
ELECTRICAL SCHEMATIC:



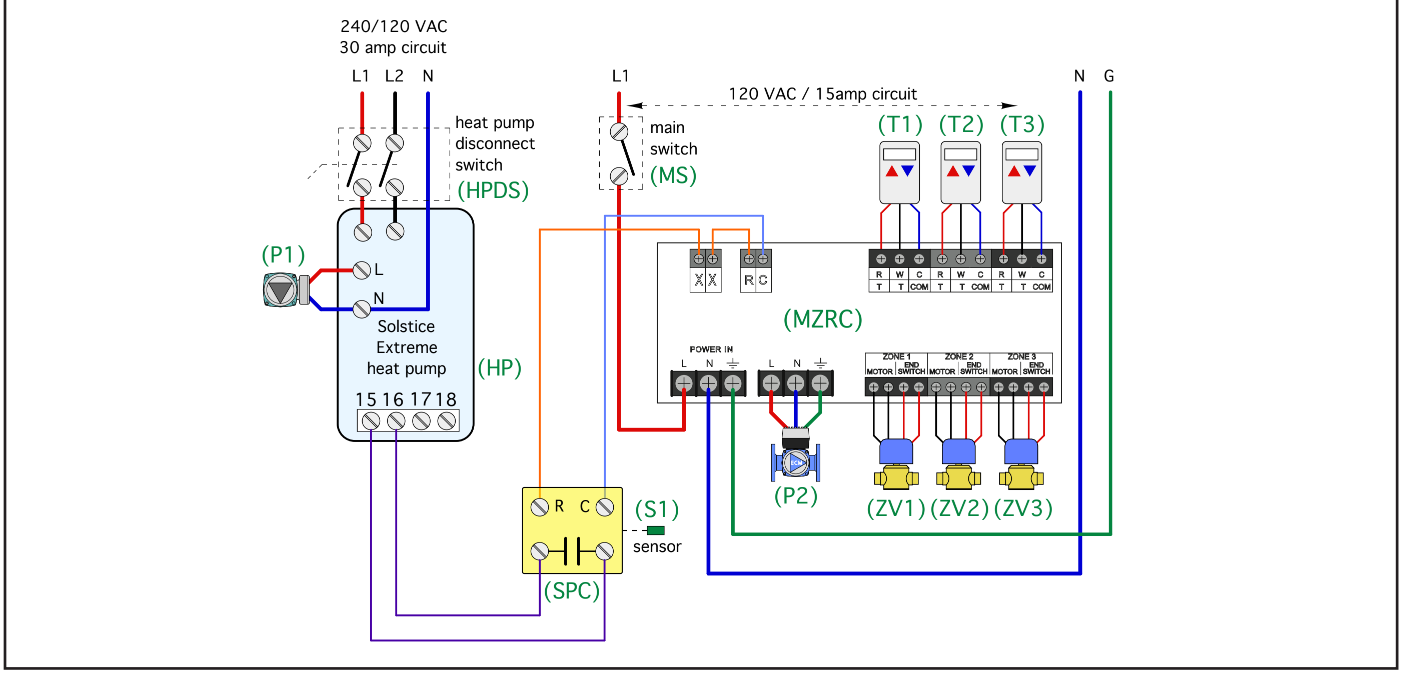
SYSTEM #2:

DESCRIPTION: This system provides space heating using a Solstice Extreme heat pump to supply three zones of low-temperature fin-tube baseboard heat emitters. The baseboard has been sized to provide design heating load to each zone using a supply water temperature of 115ºF. Flow to each zone is controlled by a standard zone valve. A variable-speed pressure-regulated circulator provides flow to the distribution system. It has been set to the differential pressure required when all three zones are operating, and automatically reduces speed when only one or two zones are operating. A buffer tank is used to prevent heat pump short cycling. The buffer tank is piped in a 3-pipe configuration. It provides hydraulic separation between the heat pump circulator and variable-speed distribution circulator. The entire system is filled with a 30% inhibited propylene glycol antifreeze solution. Two bidirectional fill/purging valves are provided to allow the antifreeze solution to be pumped into the boiler circuit and distribution circuits, and to allow for subsequent air purging.

PIPING SCHEMATIC:



ELECTRICAL SCHEMATIC:



Description of operation:

Power supply: The Solstice Extreme heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power. The remainder of the electrical system is powered by a 120 VAC 15 amp circuit. The main switch (MS) must be closed to provide power.

Space heating distribution: When a call for heat comes from any of the three zone thermostats (T1, T2, T3), the multi-zone relay center (MZRC) turns on the associated zone valve(s) (ZV1, ZV2, ZV3). It also turns on circulator (P2), which is a variable-speed circulator operating in constant differential pressure mode. It also closes a relay contact between its (X X) terminals. This contact closure supplies 24 VAC to the temperature setpoint controller (SPC) which monitors the temperature of the buffer tank at sensor (S1). The normally open relay contact in the (SPC) closes when the temperature at sensor (S1) is less than 110ºF, and opens its contacts when the temperature at sensor (S1) reaches 120ºF.

Heat pump operation: When the normally open relay contact in (SPC) closes, a circuit is completed between terminals 15 and 16 in the Solstice Extreme heat pump, turning it on in heating mode. After a short time delay, circulator (P1) is supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump measures flow using its internal flow switch, and when adequate flow is proven, starts the heat pump's refrigeration system in heating mode. The heat pump continues to operate until: 1) the (SPC) detects that the temperature at sensor (S1) has reaches its high limit, 2) the heat pump's internal high-limit temperature setting is reached, or 3) none of the thermostats are calling for heat.

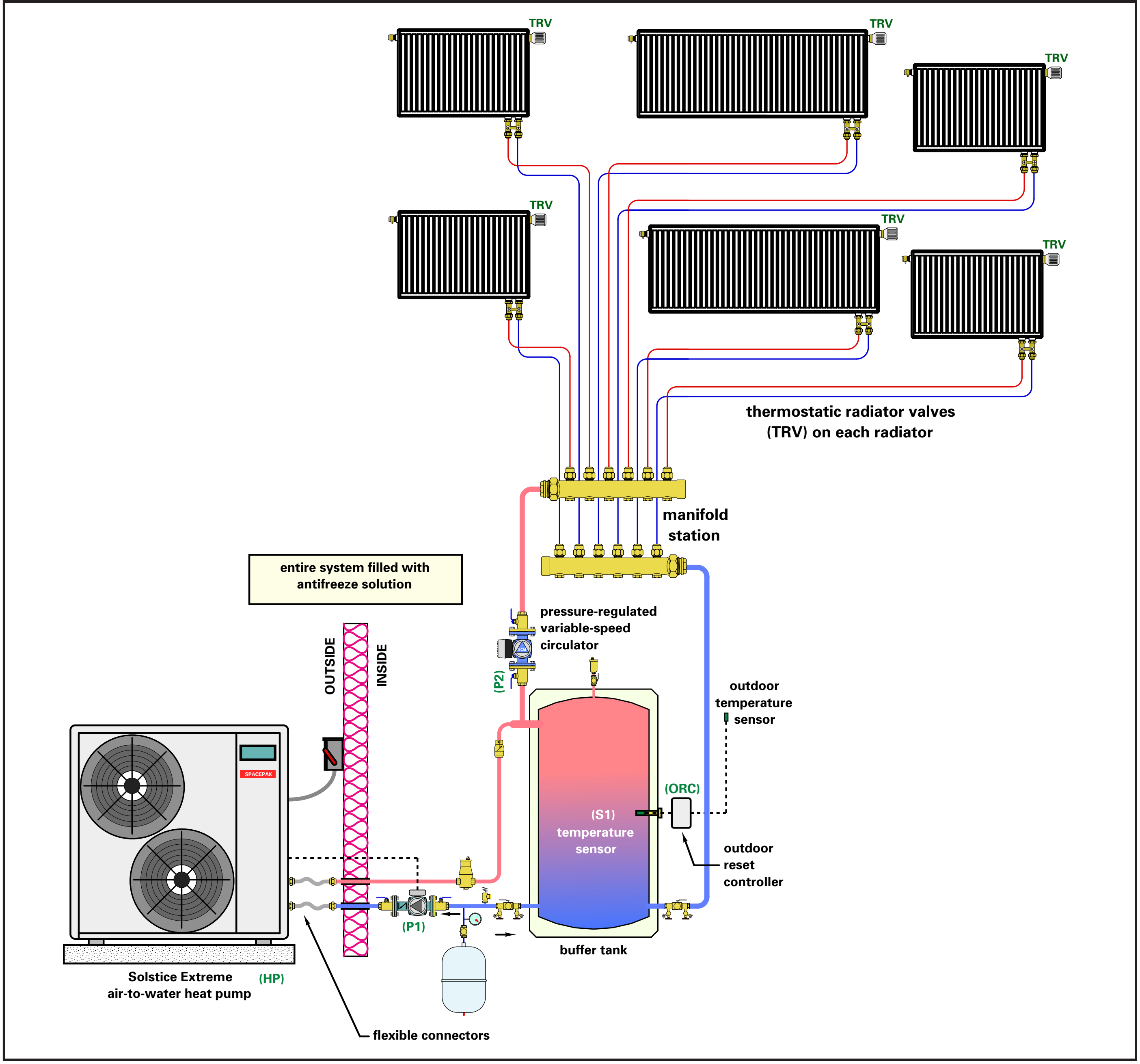
POSSIBLE CONTROLLER SETTINGS:

Temperature at sensor (S1) when (SPC) contact closes = 110ºF
Temperature at sensor (S1) when (SPC) contact opens = 120ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125ºF

SYSTEM #3:

DESCRIPTION: This system supplies space heating using a Solstice Extreme heat pump. The heat emitters are panel radiators. Each radiator has been sized to provide design heating load to the room it serves when supplied with fluid at 120ºF. The panel radiators in each room are served by individual homerun circuits of 1/2" PEX tubing. Individual room temperatures are limited by a non-electric thermostatic radiator valve on each panel radiator.

PIPING SCHEMATIC:



All flow to the distribution system is provided by a variable-speed pressure-regulated circulator. That circulator is set for the differential pressure needed when all homerun circuits are operating simultaneously. The circulator automatically adjusts speed as the thermostatic radiator valves on each radiator open, close or modulate flow.

The Solstice heat pump is *enabled* to operate whenever the outdoor temperature is below 55ºF. This "enabling" outdoor temperature can be adjusted higher or lower depending on the building characteristics and the comfort preferences of the occupants. Whenever the outdoor temperature is at or below the enabling temperature, the heat pump is turned on when the water temperature at the mid-height sensor in the buffer tank drops below 115ºF. It continues to operate until the water temperature at this sensor reaches 125ºF, or the outdoor temperature rises above the enabling temperature, or the heat pump reaches its internal high-temperature limit.

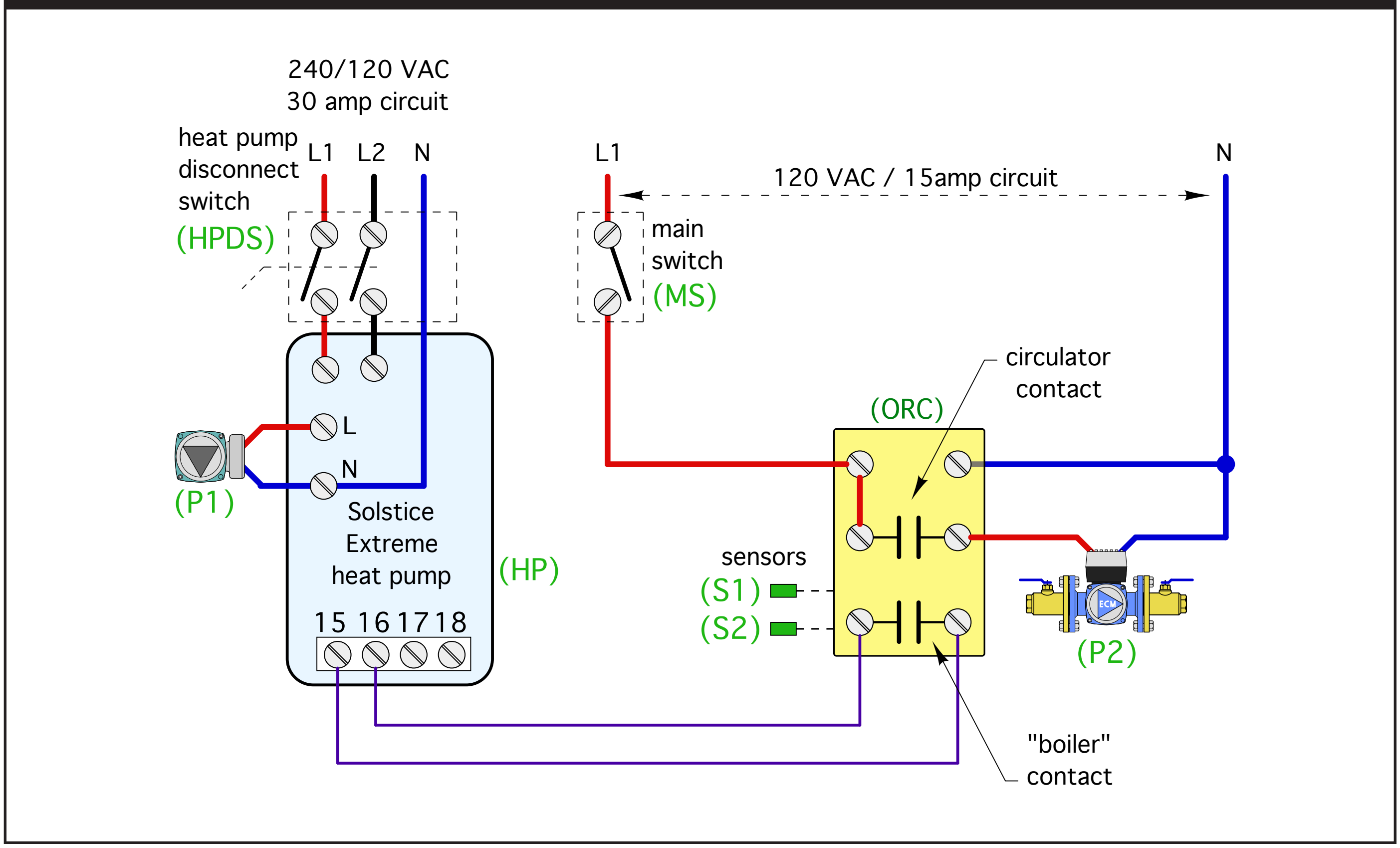
The buffer tank is piped in a "3-pipe" configuration, allowing it to provide hydraulic separation between the heat pump circulator and the distribution circulator. This configuration also allows heated fluid from the heat pump to flow directly to the load when necessary, without having to first warm the buffer tank.

The entire system operates with a 30% solution of propylene glycol antifreeze.

Description of operation:

Power supply: The Solstice Extreme heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power. The remainder of the electrical system is powered by 120 VAC 15 amp circuit. The main switch (MS) must be closed to provide power.

ELECTRICAL SCHEMATIC:



Heating Distribution: Whenever the outdoor temperature drops below the "enabling" temperature (suggested as 55ºF), the outdoor reset controller (ORC) turns on the variable-speed circulator (P2). This circulator operates in constant differential pressure mode, automatically regulating its motor speed to maintain the set differential pressure as the thermostatic radiator valves on each heat emitter open, close or modulate flow. Heated water passes through any distribution circuit in which the thermostatic radiator valve is partially or fully open. Individual room temperature is regulated by the thermostatic radiator valves on each radiator.

Heat Pump Operation: Whenever the outdoor temperature drops below the "enabling" temperature (suggested as 55ºF), the outdoor reset controller measures the current outdoor temperature at sensor (S2), and uses this value, along with its settings, to calculate the target water temperature for the buffer tank. It then compares the calculated target temperature to the measured temperature of the buffer tank at sensor (S1). The (ORC) closes its "boiler" contact if the measured tank temperature is 5ºF or more below the current calculated target temperature for the tank. The closed contact completes a circuit between terminals 15 and 16 on the heat pump. After a short time delay, the heat pump turns on circulator (P1). The heat pump then measures the flow rate through its internal flow switch, and if adequate flow is proven, starts the refrigeration system in heating mode. This operation continues until the measured temperature at sensor (S1) is 5ºF above the current target temperature, or the outdoor temperature climbs above the enabling temperature, or the heat pump reaches its internal high-limit setting.

POSSIBLE CONTROLLER SETTINGS:

Outdoor design temperature = 10ºF
Outdoor temperature where (ORC) enables system to operate = 55ºF
Target temperature at tank sensor (S1) at design conditions = 120ºF
Target temperature at tank sensor (S1) at no load = 70ºF
Minimum temperature to be maintained at sensor (S1) = 80ºF
(ORC) "boiler" contacts open when sensor (S1) = [target temperature + 5ºF]
(ORC) "boiler" contacts close when sensor (S1) = [target temperature - 5ºF]
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125ºF

SYSTEM #4:

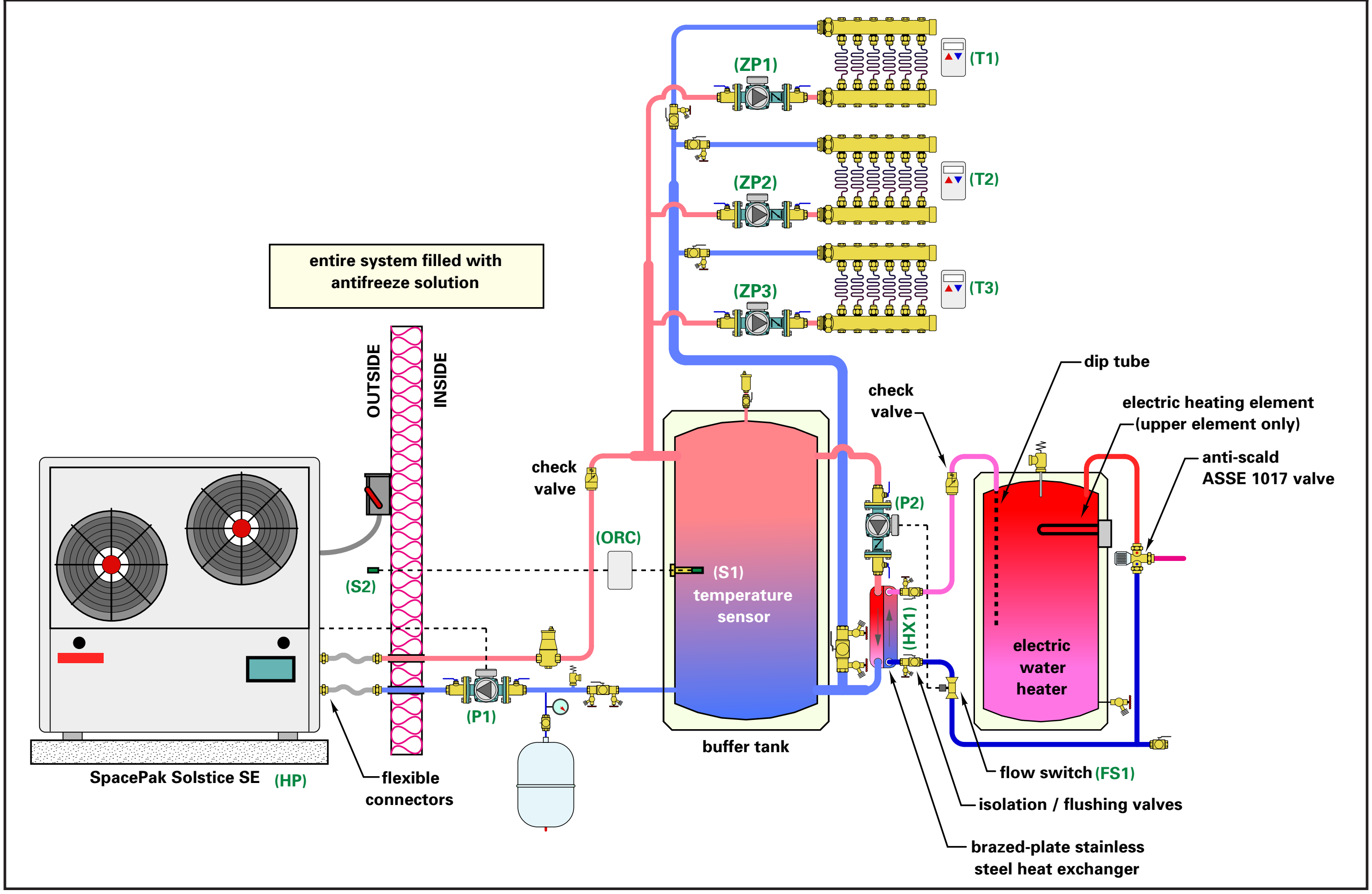
DESCRIPTION: This system provides space heating and domestic hot water using a Solstice SE heat pump to supply 3 zones of low-temperature radiant panel heating. Flow to each radiant panel zone is provided by a zone circulator. A buffer tank is used to prevent heat pump short cycling when only one or two zones are operating. The buffer tank is piped in a 3-pipe configuration. As such, it provides hydraulic separation between the heat pump circulator (P1), the zone circulators (ZP1, ZP2, ZP3), and circulator (P2). It also allows the warmest fluid leaving the heat pump to flow directly to the load when necessary. The entire system is filled with a 30% inhibited propylene glycol antifreeze solution. Two bidirectional fill/purging valves are provided to allow the antifreeze solution to be pumped into the boiler circuit and distribution circuits, and for subsequent air purging.

Domestic water is preheated using heat from the buffer tank through a stainless steel plate heat exchanger. Flow from the buffer tank to the heat exchanger is controlled by a domestic hot water flow switch. The preheated water flows into a standard tank-type domestic water heater where the water temperature is raised (if necessary) to the desired delivery temperature.

Description of operation:

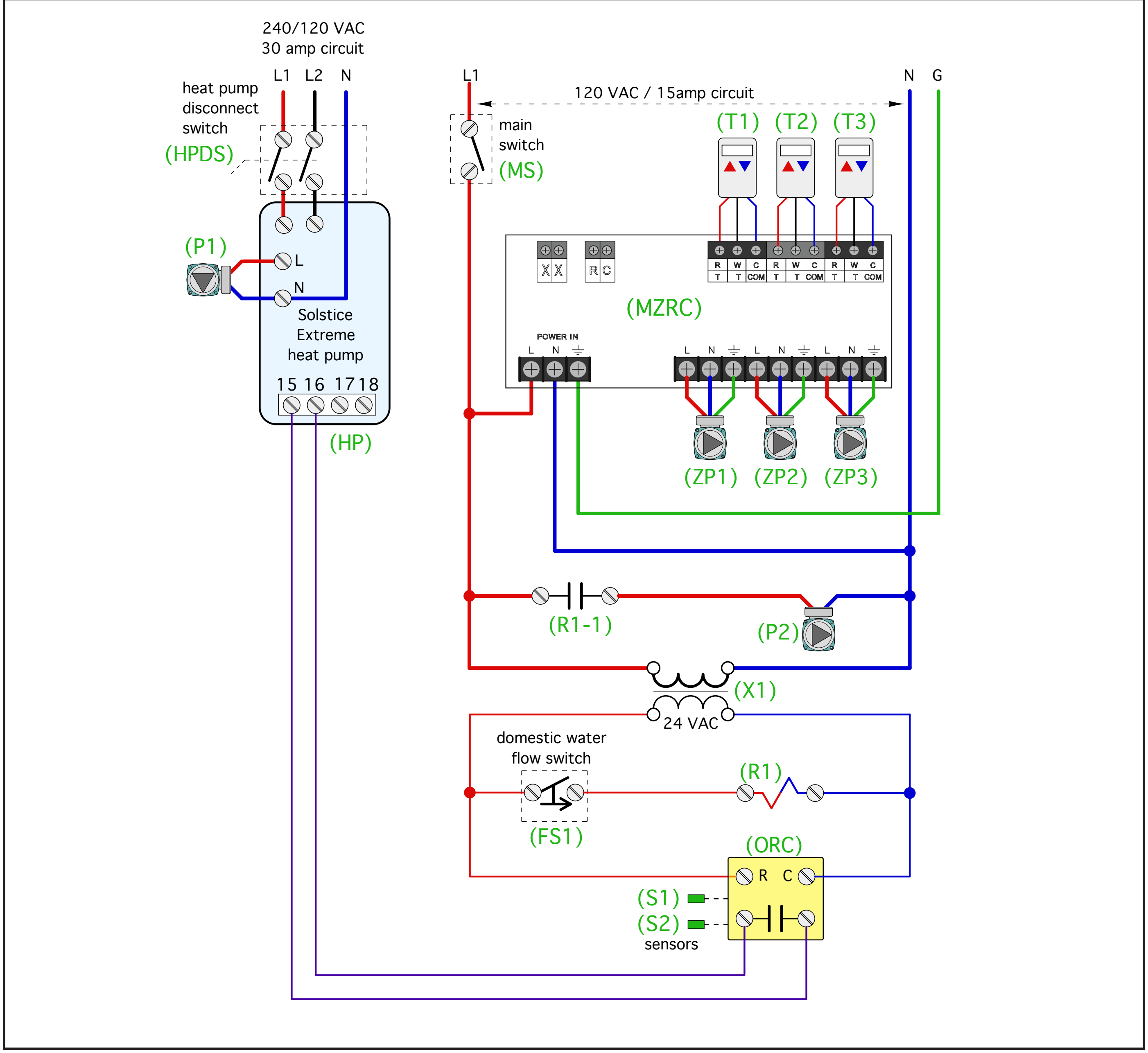
Power supply: The Solstice heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power. The remainder of the control system is powered by 120 VAC 15 amp circuit. The main switch (MS) must be closed to provide power. The electric water heater is supplied by a dedicated 240 VAC / 30 amp circuit.

PIPING SCHEMATIC:



Heat pump operation: Whenever the main switch (MS) is closed 120 VAC is passed to the multi-zone relay center (MZRC) and transformer (X1). The (MZRC) passes 24 VAC to all three thermostats (T1, T2, T3). 24 VAC from transformer (X1) also powers on the outdoor reset controller (ORC). The (ORC) measures the outdoor temperature at sensor (S2) and uses it, along with its settings, to calculate the target temperature of the buffer tank. The (ORC) also monitors the temperature of the buffer tank at sensor (S1). When the temperature at sensor (S1) drops 5ºF or more below the calculated target

ELECTRICAL SCHEMATIC:



temperature, the normally open relay contact in the (ORC) closes. This completes a circuit between terminals 15 and 16 in the Solstice Extreme heat pump, enabling it to operate in heating mode. After a short time delay, circulator (P1) will be supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal flow switch, and when adequate flow is proven, starts the heat pump in heating mode. The system continues in this mode until the temperature at sensor (S1) reaches 5°F above the calculated target temperature, or the heat pump reaches its internal high-limit temperature. *Note: Because the buffer tank is also being used to preheat domestic water, its temperature is maintained at conditions determined by the outdoor reset controller (ORC) regardless of the status of any space-heating thermostats.*

Domestic water heating: Whenever there is draw of domestic hot water, cold domestic water passes through the flow switch (FS1). This switch closes its contact whenever flow reaches 0.7 gallons per minute or higher. This passes 24 VAC through relay coil (R1). Relay contact (R1-1) closes to supply 120 VAC to circulator (P2). Heated water from the buffer tank passes through the brazed-plate stainless steel heat exchanger (HX1) and transfers heat to the domestic water. The heat exchanger (HX1) has been sized to provide a 5°F approach temperature difference. The domestic water leaving (HX1) should be heated to approximately 5°F less than the water temperature at the top of the buffer tank. This water passes into the dip tube of the electric water heater. Any additional temperature rise of the domestic water is provided by the upper electric heating element in the water heater.

POSSIBLE CONTROLLER SETTINGS:

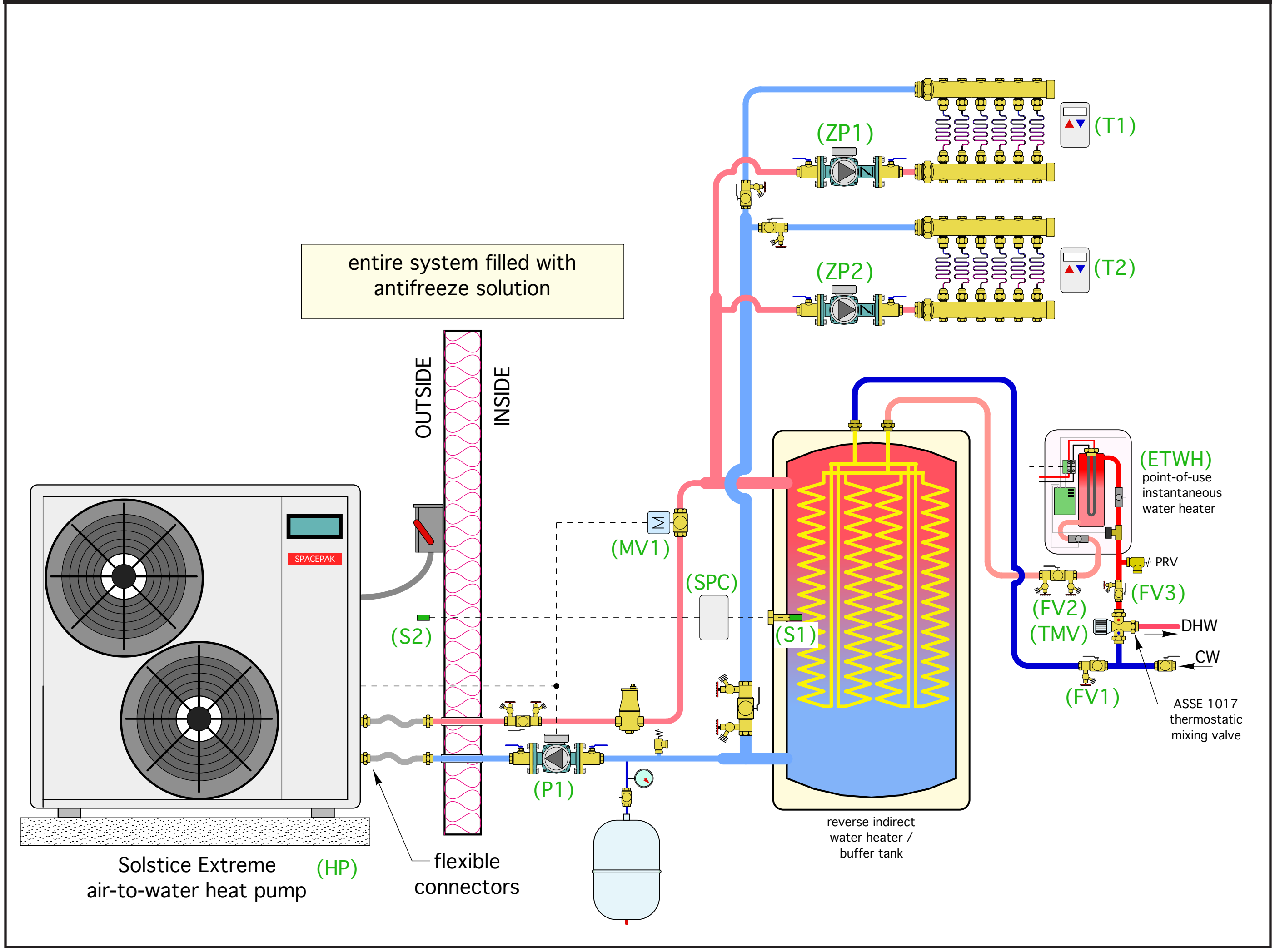
Outdoor design temperature = 10°F
Outdoor temperature corresponding to no load = 70°F
Target temperature at sensor (S1) at design conditions = 100°F
Target temperature at sensor (S1) at no load = 70°F
Minimum temperature to be maintained at sensor (S1) = 85°F
(ORC) contacts open when sensor (S1) = [target temperature + 5°F]
(ORC) contacts close when sensor (S1) = [target temperature - 5°F]
Thermostat in DHW tank setting = 120°F
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130°F
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125°F

SYSTEM #5:

DESCRIPTION: This system provides space heating and domestic hot water using a Solstice Extreme heat pump to supply two zones of medium-temperature radiant panel heating (e.g., the radiant panels require 115ºF at design load conditions). The majority of the domestic water heating takes place within copper coil heat exchangers suspended within the buffer tank. This tank configuration is sometimes called a "reverse indirect water heater." *The heat pump maintains the tank temperature between 105ºF and 125ºF at all times.* The average water temperature of the buffer tank (115ºF) allows the radiant panel system to provide design load through the radiant panels. Any supplemental heating of domestic water is provided by the tankless electric water heater, which turns on when flow of domestic water reaches 0.7 gpm, and modulates electrical power to its heating elements as necessary to achieve and maintain the desired supply water temperature. An ASSE 1017 valve prevents water temperatures higher than 120ºF from being delivered to hot water fixtures.

The tank is piped in a "2-pipe" configuration (due to tank availability). A motorized ball valve is installed between the heat pump and tank. This valve opens when the heat pump circulator is operating and closes at all other times. This

PIPING SCHEMATIC:



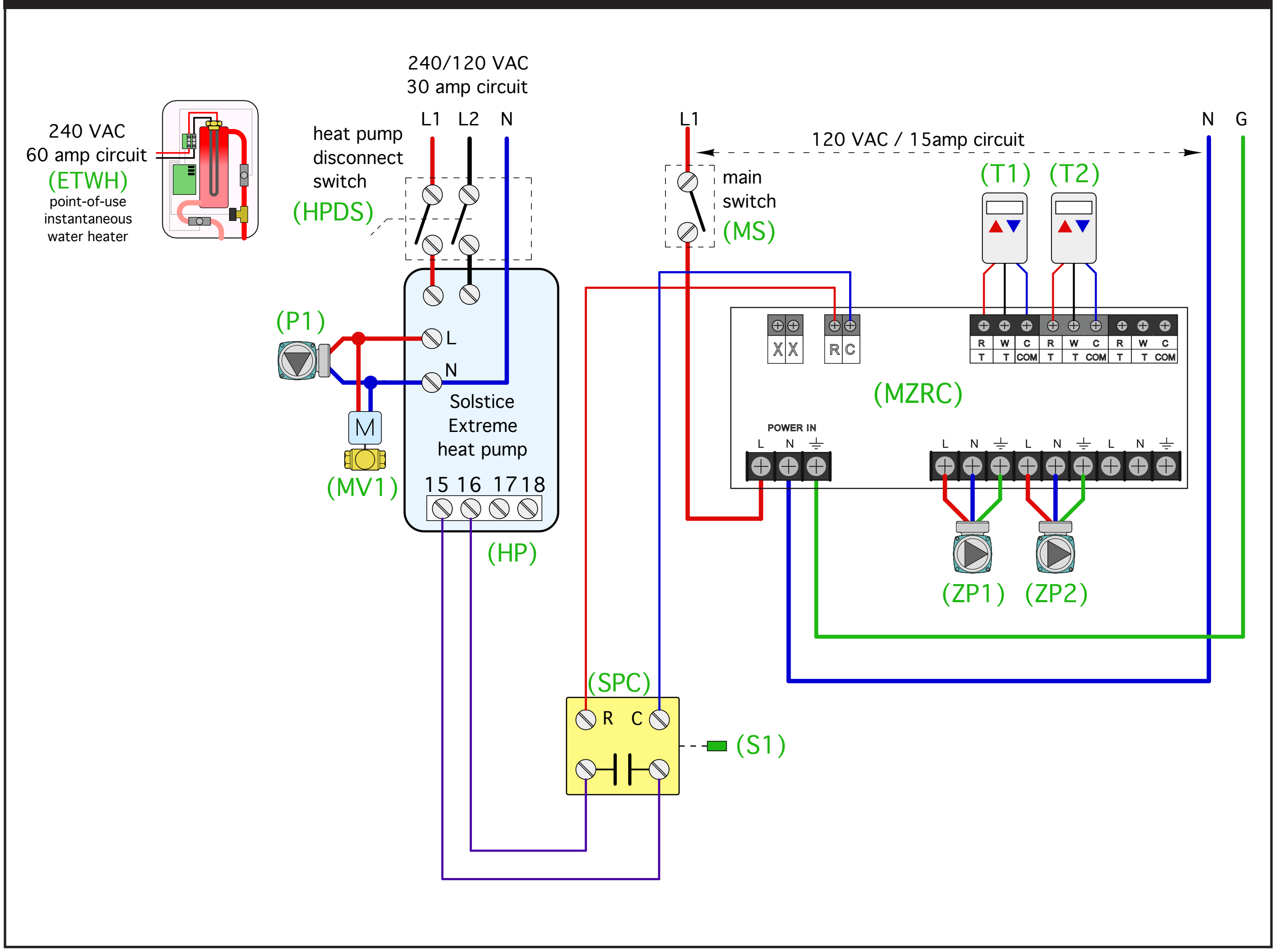
prevents unintentional flow through the heat pump when it is off, and the buffer tank is supplying heat to the load.

Description of operation:

Power supply: The Solstice heat pump, circulator (P1) and motorized valve (MV1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power. The remainder of the control system is powered by 120 VAC 15 amp circuit. The main switch (MS) must be closed to provide power. The instantaneous water heater is supplied by a dedicated 240 VAC/60 amp circuit.

Heat pump operation: Whenever the main switch (MS) is closed, 120 VAC is passed to the multi-zone relay center (MZRC). The (MZRC) passes 24 VAC to the temperature setpoint controller (SPC), which monitors the temperature at sensor (S1) in the buffer tank. If the temperature at sensor (S1) is below 105ºF, the (SPC) closes its contact, which completes a circuit between terminals 15 and 16 in the Solstice Extreme heat pump, enabling it to operate in heating mode. After a short time delay, circulator (P1) and motorized valve (MV1) will be supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal

ELECTRICAL SCHEMATIC:



flow switch, and when adequate flow is proven, starts the heat pump in heating mode. The 120 VAC supplied to (MV1) opens the valve, allowing flow between the heat pump and the headers of the thermal storage tank. The system continues in this mode until the temperature at sensor (S1) reaches 125ºF, at which point the contacts in the setpoint controller (SPC) open, turning off the heat pump, circulator (P1) and motorized valve (MV1).

Space heating: Whenever the main switch (MS) is closed, 24 VAC is sent to the thermostats (T1,T2). When either thermostat calls for heating, its associated zone circulator (ZP1, ZP2) is turned on.

Domestic water heating: Domestic water passes through the copper tubing coils suspended in the buffer tank. The tank temperature at sensor (S1) is maintained between 105 and 125ºF. Domestic water passing through the coil will be preheated (or at times fully heated) as it passes through this coil. Any additional temperature rise of the domestic water is provided by the tankless electric water heater.

Flush valves (FV1, FV2, FV3) allow the internal coils in the tank, as well as the instantaneous water heater (ETWH) to be isolated and chemically flushed if necessary to remove accumulated scale.

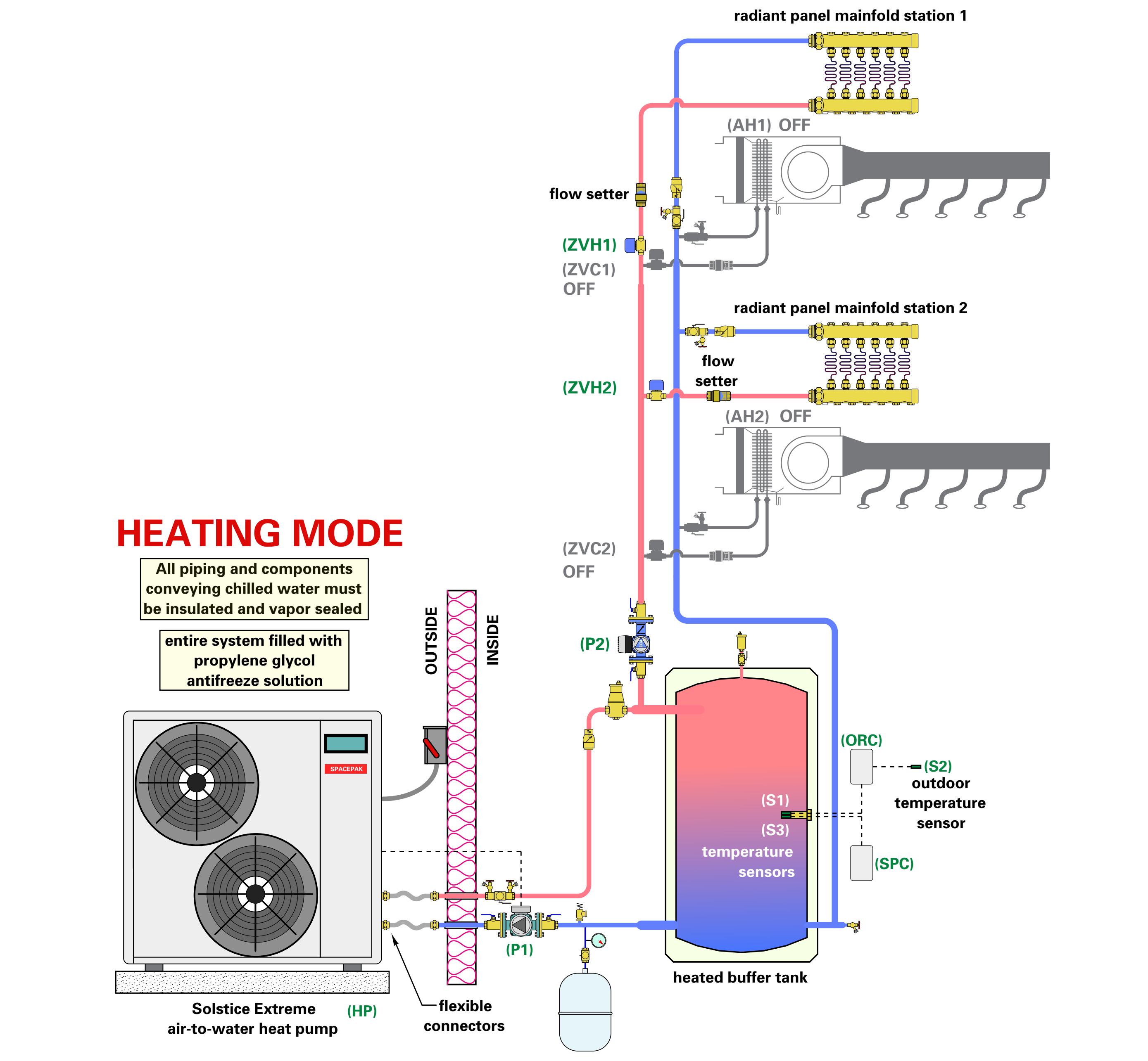
POSSIBLE CONTROLLER SETTINGS:

Temperature at sensor (S1) when heat pump turns on = 105ºF
Temperature at sensor (S1) when heat pump turns off = 125ºF
Temperature setting of the instantaneous water heater = 120ºF
Temperature setting of the ASSE 1070 mixing valve = 120ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 127ºF

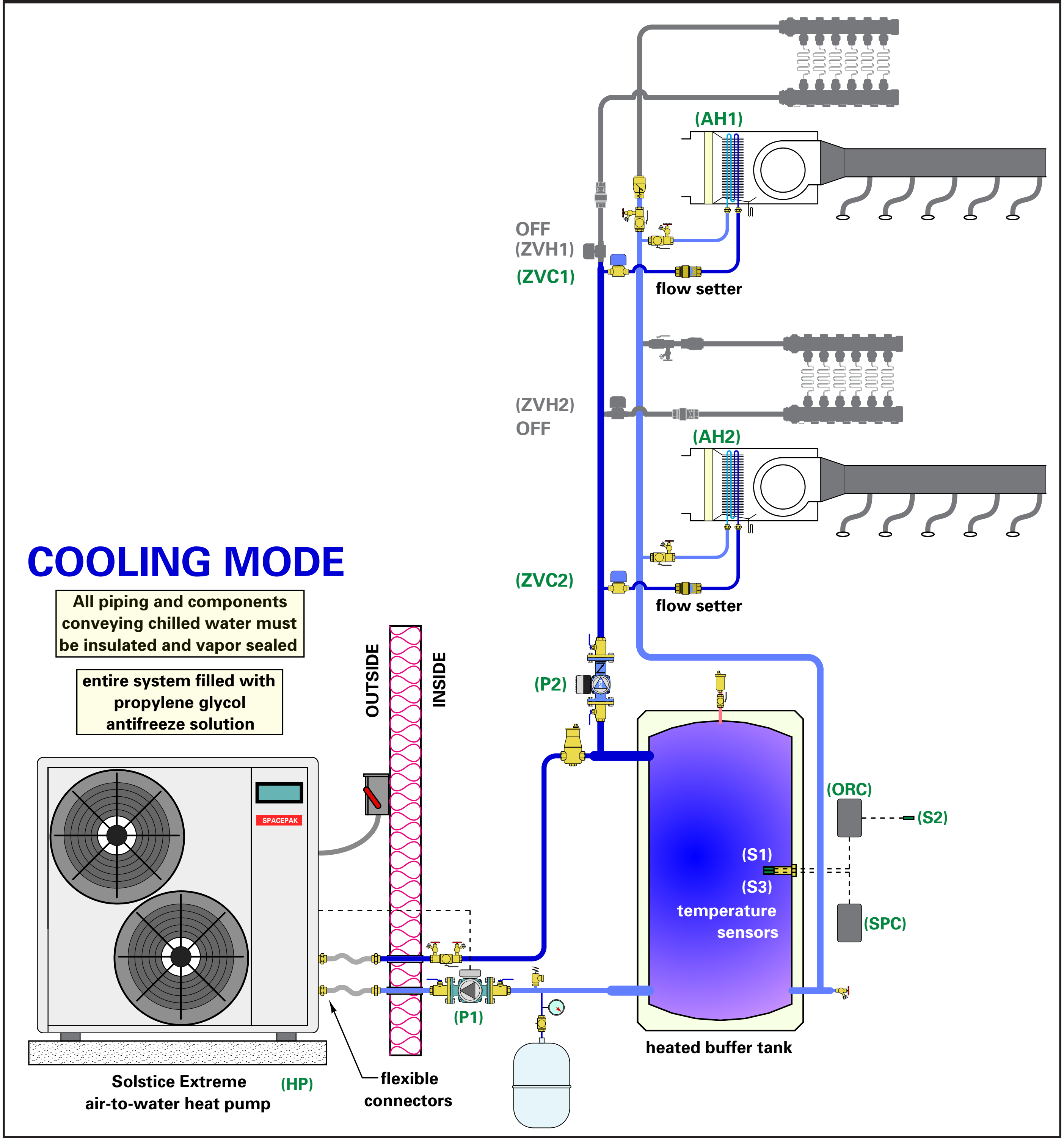
SYSTEM #6:

Description: This system provides two independent zones of heating and cooling. Both zones must operate in the same mode at the same time. Space heating is provided by radiant panels. Cooling is provided by two SpacePak WCSP-J air handlers. Flow to all heating and cooling zones is provided by a single variable-speed pressure-regulated circulator that automatically changes speed to maintain constant differential pressure regardless of which zone(s) are operating.

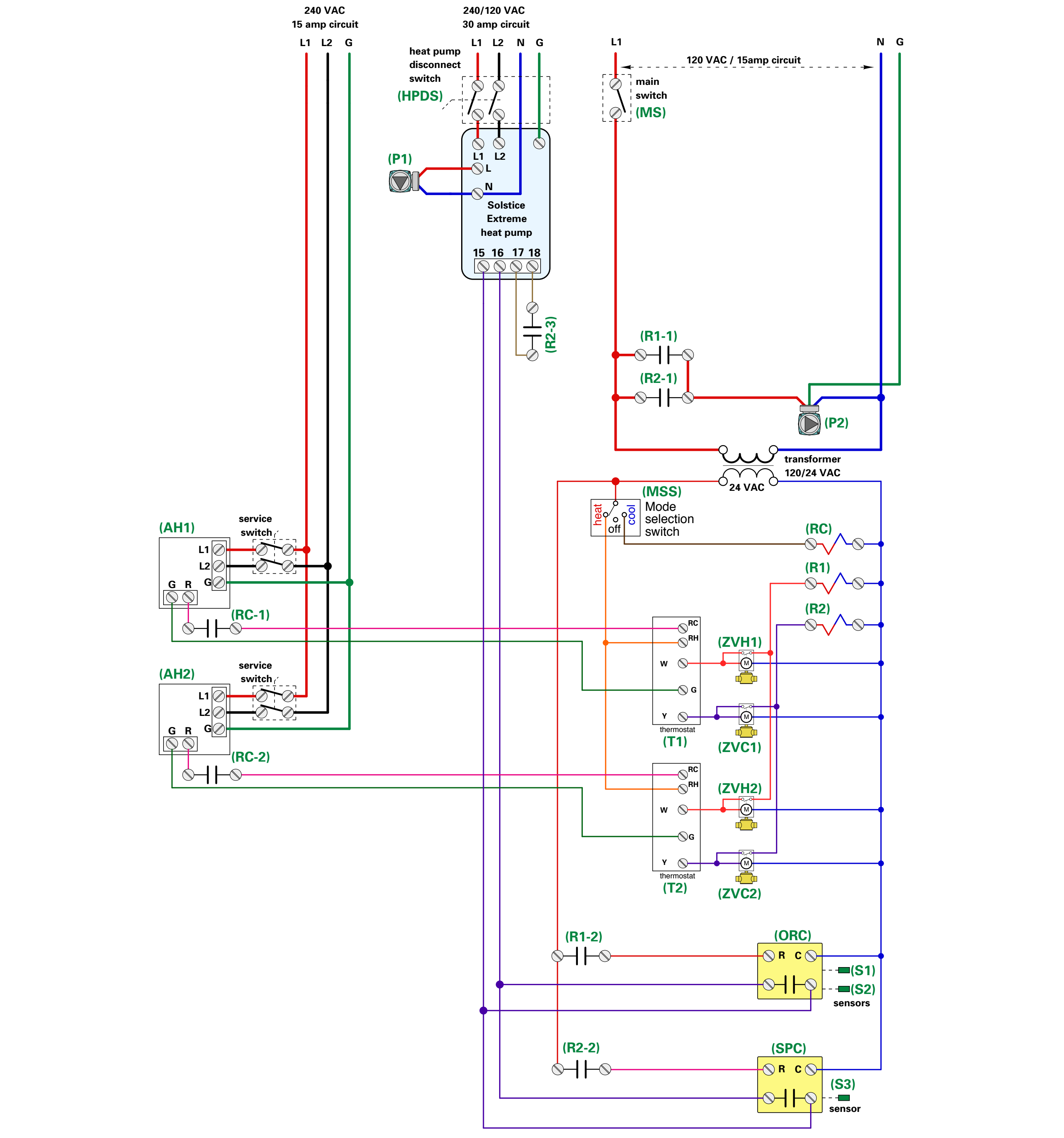
PIPING SCHEMATIC (HEATING MODE):



PIPING SCHEMATIC (COOLING MODE):



ELECTRICAL SCHEMATIC:



During heating mode operation, the fluid temperature in the buffer tank is determined by an outdoor reset controller. The maximum target water temperature at the mid-height sensor (S1) in the buffer tank is 110ºF, corresponding to an outdoor temperature of 0ºF. The minimum target water temperature at sensor (S1) is 80ºF, corresponding to an outdoor temperature of 52.5ºF or higher. Outdoor reset control of the buffer tank temperature allows the system to meet the heating load of the building while maintaining the lowest possible water temperature required of the heat pump, which maximizes its coefficient of performance.

During cooling mode, the temperature of the fluid in the buffer tank is maintained between and upper and lower limit by a setpoint controller.

The buffer tank piping is optimized to preserve stratification during heating mode operation.

All piping carrying chilled fluid must be insulated and vapor sealed. Migration of chilled water into either radiant panel zone is prevented by a combination of a closed zone valve on the supply pipe to the manifold station and a check valve on the return side piping.

The entire system is filled with a 30% solution of inhibited propylene glycol antifreeze.

Description of operation:

Power supply: The Solstice Extreme heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power to the heat pump. The remainder of the control system is powered by 120 VAC/15 amp circuit. The main switch (MS) must be closed to provide power to the control system. Both fan-coils are powered by a dedicated 240 VAC/15 amp circuit. The service switch for each air handler must be closed for that air handler to operate.

Heating mode: The mode selection switch (MSS) must be set for heating. This passes 24 VAC to the RH terminal in each thermostat. Whenever either thermostat (T1, T2) demands heat, 24 VAC is passed from the thermostat's W terminal to the associated heating zone valve (ZVH1 or ZVH2). When the zone valve reaches its fully open position, its internal end switch closes, passing 24 VAC to relay coil (R1). Relay contact (R1-1) closes to pass 120 VAC to circulator (P2). Relay contact (R1-2) closes to pass 24 VAC to the outdoor reset controller (ODR). The (ODR) measures outdoor temperature at sensor (S2), and uses this temperature, along with its settings, to calculate the target supply water temperature for the buffer tank. It then measures the temperature of the buffer tank at sensor (S1). If the temperature at (S1) is more than 3ºF below the target temperature, the (ODR) closes its relay contact. This completes a circuit between terminals 15 and 16 in the Solstice extreme heat pump, enabling it in heating mode. After a short time delay, the heat pump (HP) turns on circulator (P1) and verifies adequate flow through the heat pump. After a short time delay, the heat pump turns on it compressor. The heat pump continues to operate until the temperature at sensor (S1) is 3ºF above the target temperature calculated by the (ODR), or neither thermostat calls for heat, or the heat pump reaches its internal high-limit setting. *Note: Neither air handler operates in heating mode, regardless of the fan switch setting on the thermostats.*

Cooling mode: The mode selection switch (MSS) must be set for cooling. This passes 24 VAC to relay coil (RC). Normally open contacts (RC-1) and (RC-2) close, allowing 24 VAC from the air handlers to pass to the RC terminal in each thermostat (T1, T2). Whenever either thermostat calls for cooling, 24 VAC is passed from the thermostat's Y terminal to the associated cooling zone valve (ZVC1 or ZVC2). When the zone valve reaches its fully open position, its internal end switch closes, passing 24 VAC to relay coil (R2). Relay contact (R2-1) closes to pass 120 VAC to circulator (P2). Relay contact (R2-2) closes to pass 24 VAC to the cooling setpoint controller (SPC). The cooling setpoint controller measures the temperature of the buffer tank at sensor (S3). If this temperature is 60ºF or higher, the (SPC) relay contact closes, completing a circuit between terminals 15 and 16 on the Solstice Extreme heat pump (HP) enabling it to operate. Relay contact (R2-3) closes between terminals 17 and 18 in the Solstice Extreme heat pump (HP), switching it to cooling mode. The heat pump (HP) turns on circulator (P1) and verifies adequate flow through the heat pump. After a short time delay, the heat pump compressor turns on it compressor and operates in chiller mode. This continues until the temperature at sensor (S3) drops to

45ºF, or until neither zone thermostat calls for cooling, or until the heat pump reaches in internal low-limit setting. The blowers in the air handlers can be manually turned on at the thermostats when the mode selection switch (MSS) is set to cooling. The blowers will operate automatically whenever either cooling zone is active.

Distribution: Circulator (P2) is a variable speed pressure-regulated circulator that is set for the required differential pressure when both heating zones, or both cooling zones, are operating. It will automatically reduce speed to maintain a constant differential pressure when only one heating zone, or one cooling zone is operating. Automatic flow balancing valves with present flow rates, are installed on both heating zone circuits and both cooling zone circuits.

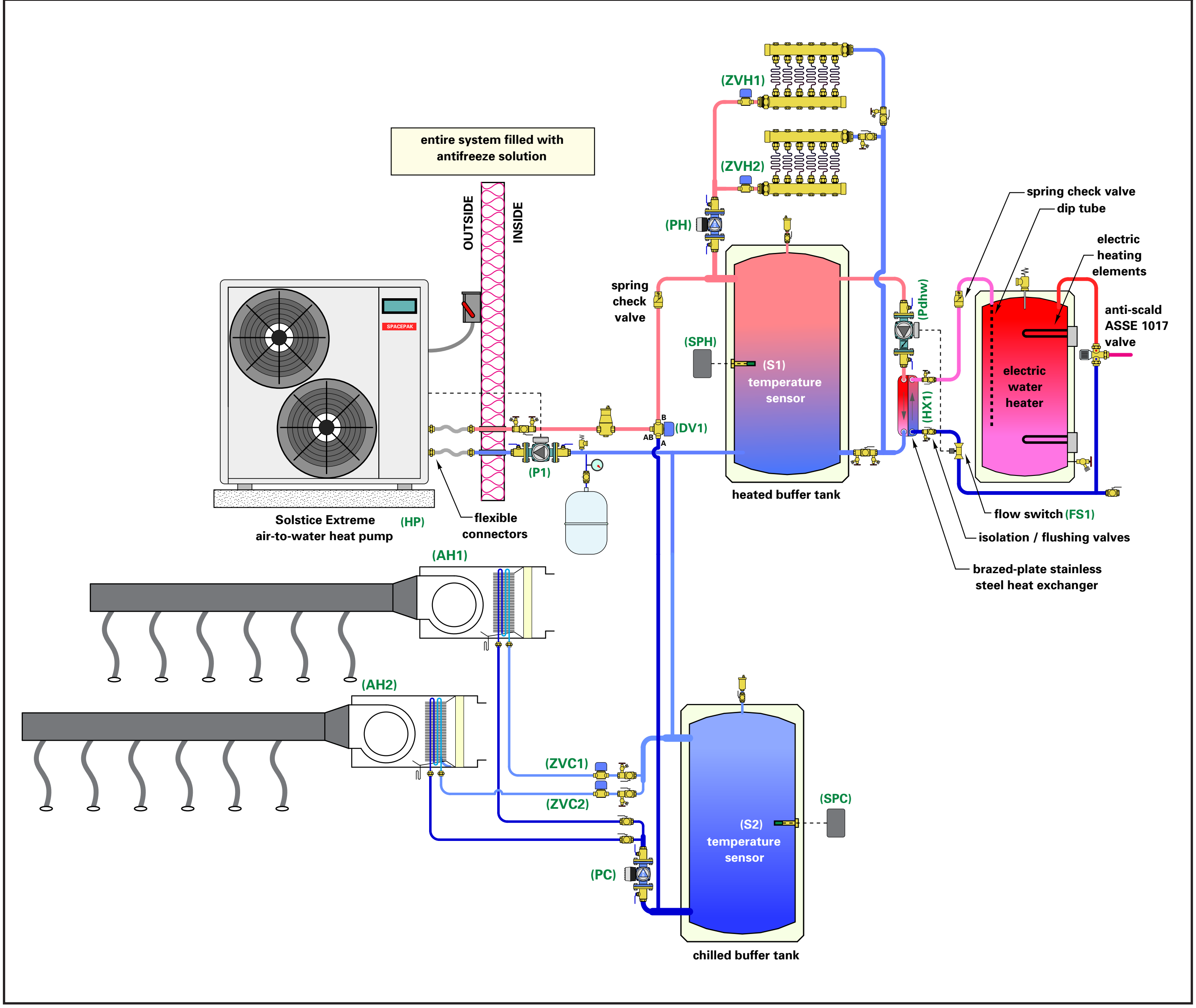
POSSIBLE CONTROLLER SETTINGS:

Outdoor design temperature = 0ºF
Outdoor temperature corresponding to no heating load = 70ºF
Target temperature at sensor (S1) at heating design conditions = 110ºF
Target temperature at sensor (S1) at no heating load = 70ºF
Minimum temperature to be maintained at sensor (S1) = 80ºF
(ORC) contacts open when sensor (S1) = [target temperature + 3ºF]
(ORC) contacts close when sensor (S1) = [target temperature - 3ºF]
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125ºF
Temperature at sensor (S1) for heat pump on (cooling mode) = 60ºF
Temperature at sensor (S1) for heat pump off (cooling mode) = 45ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≤ 41ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≥ 45ºF

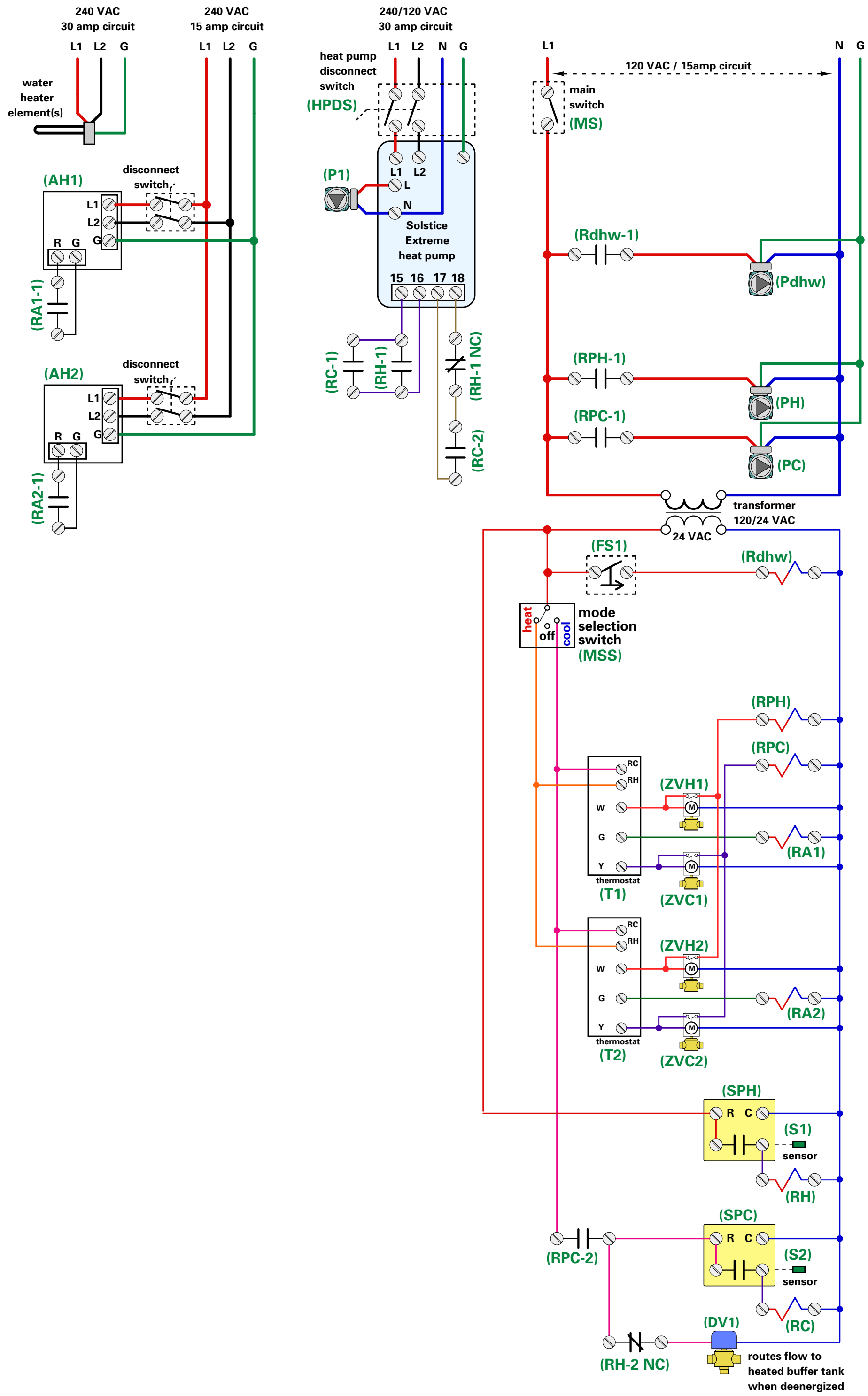
SYSTEM #7:

Description: This system provides two zones of low-temperature radiant panel heating, two zones of chilled-water cooling and domestic hot water. It uses two buffer tanks: one for heating and the other for cooling. A mode selection switch determines in which mode the system operates. A single thermostat in each zone controls the system in both heating and cooling modes. The majority of the domestic water-heating load is provided by the Solstice heat pump. Any supplemental domestic water heating is provided by a standard tank-type water heater with an electric element. System controls are configured so that the system will temporarily leave cooling mode to maintain the heated buffer tank between 100ºF and 120ºF, and thus, provide "prioritized" energy input for domestic water heating. The time required to restore the heated buffer tank from 100ºF to 120ºF during

PIPING SCHEMATIC:



ELECTRICAL SCHEMATIC:



the cooling season, will typically only be a few minutes. During this time, chilled fluid from the cooling buffer tank can still pass through the air handlers for cooling. The system controls have been configured so that each air handler is turned on by a dry contact closure. The air handler in each zone can operate during heating mode (if desired). If the air handlers are to remain off during heating, their service switches can be turned off.

Description of operation:

Power supply: The Solstice Extreme heat pump and circulator (P1) are powered by a dedicated 240/120 VAC / 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power to the heat pump. The remainder of the control system is powered by 120 VAC/15 amp circuit. The main switch (MS) must be closed to provide power to the control system. Both air handlers are powered by a dedicated 240 VAC/15 amp circuit. The disconnect switch for each air handler must be closed for that air handler to operate. The electric water heater is supplied by a dedicated 240 VAC / 30 amp circuit.

Heat pump operation (heating mode): Whenever the main switch (MS) is closed, 24 VAC is passed to the heating setpoint controller (SPH), which monitors the temperature of the buffer tank at sensor (S1). When the temperature at sensor (S1) drops below 100ºF, the contacts in (SPH) close. This completes a circuit between terminals 15 and 16 in the Solstice Extreme heat pump, enabling it to operate in heating mode. After a short time delay, circulator (P1) is supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal flow switch, and when adequate flow is proven, starts the heat pump in heating mode. The system continues in this mode until the temperature at sensor (S1) reaches 120ºF, or the heat pump reaches its internal high-temperature limit, at which point the heat pump turns off. The motorized diverter valve (DV1) is off during heating mode. Flow passes from its AB port to its B port (e.g., from the heat pump to the heated buffer tank).

Heat pump operation (cooling mode): The mode selection switch must be set to cooling. The mode selection switch on the thermostats (T1, T2) must also be set for cooling. Whenever either thermostat (T1, T2) calls for cooling, 24 VAC is passed from the Y terminal of the thermostat to the associated zone valves (ZVC1 or ZVC2), causing that valve to open. When the valve is fully open, its internal end switch closes. 24 VAC is passed through the end switch to energize relay (RPC). The normally open contact (RPC-2) closes, passing 24 VAC to the cooling setpoint controller (SPC), which measures the temperature in the chilled buffer tank at sensor (S2). If the temperature at (S2) exceeds 60ºF, the normally open contact in (SPC) closes, passing 24 VAC to relay coil (RC). The diverter valve (DV1) is also powered on by 24 VAC, routing flow from the AB port of the valve to the A port of the valve. This allows flow between the heat pump and chilled buffer tank. Normally open contact (RC-1) also closes between terminals 15 and 16 on the heat pump, enabling it to operate. Normally open contact (RC-2) closes across terminals 17 and 18 on the heat pump, enabling cooling mode. After a short time delay, circulator (P1) is supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal flow switch, and when adequate flow is proven, starts the heat pump compressor. The system continues in this mode until the temperature at sensor (S2) drops to 44ºF, at which point the contacts in the (SPC) open, turning off relay coil (RC), which turns off the heat pump circulator (P1) and diverter valve (DV1).

Cooling Override: If the mode selection switch is set for cooling, and there is a call from heating setpoint controller (SPH) to heat the heated buffer tank, relay contact (RH-1 NC) opens, breaking the circuit between heat pump terminals 17 and 18, putting the heat pump in heating mode. Relay contact (RH-2 NC) opens to interrupt 24 VAC to motorized diverter valve (DV1), enabling flow from the heat pump to the heated buffer tank. Relay contact (RH-1) closes, enabling the heat pump to operate in heating mode. Cooling operation is temporarily interrupted until the heated buffer tank reaches 120ºF (which will be a short time during cooling season). This ensures heat within the heated buffer tank for use in domestic water heating. Circulator (PC) can continue to deliver chilled fluid from the chilled buffer tank to the air handlers.

Space heating distribution: The mode selection switch (MSS) must be set for heating. The mode selection switch on thermostats (T1, T2) must also be set for heating. When a call for heat comes from either of the two zone thermostats (T1, T2,), 24 VAC is passed from the RH terminal of the thermostat to that thermostat's W terminal. This energizes the heating zone valves (ZVH1 or ZVH2), causing them to open. When the zone valve is fully open, its internal end switch closes. 24 VAC is passed through the end switch to energize relay coil (RPH). Normally open contact (RPH-1) closes to pass 120 VAC to heating distribution circulator (PH). Circulator (PH) is a variable-speed pressure-regulated circulator set to maintain a fixed differential pressure on the heating distribution system when either zone valve, or both zone valves are open. Heated fluid from the buffer tank is circulated through the manifold station(s) for the radiant panels. 24 VAC will also be passed from the G terminal of the thermostats to relay coils (RA1 or RA2). This will close contacts (RA1-1 or RA2-1), which would turn on the air handlers (AH1 or AH2). However, the air handlers can be prevented from operating in heating mode by turning off their disconnect switch.

Space cooling distribution: The mode selection switch (MSS) must be set for cooling. The mode selection switch on the two thermostats (T1, T2) must also be set for cooling. The disconnect switches on both air handlers must be set to on. When a call for cooling comes from either of the two zone thermostats (T1, T2,), 24 VAC is passed from the RC terminal of the thermostat to the Y terminal. This energizes the associated zone valve (ZVC1 or ZVC2), causing it to open. When the zone valve is fully open, its internal end switch closes. 24 VAC is passed through the end switch to energize relay coil (RPC). Normally open contact (RPC-1) closes to pass 120 VAC to cooling distribution circulator (PC). Circulator (PC) is a variable-speed pressure-regulated circulator set to maintain a fixed differential pressure on the cooling distribution system when either zone valve, or both zone valves, open. Circulator (PC) provides flow through the cooling distribution system. 24 VAC will also be passed from the G terminal of the thermostats to relay coils (RA1 or RA2). This will close contacts (RA1-1 or RA2-1), which turns on the blowers in the air handlers (AH1 or AH2).

Domestic water heating: Whenever there is draw of domestic hot water, cold domestic water passes through the flow switch (FS1). This switch closes its contact whenever flow reaches 0.7 gallons per minute or higher. This passes 24 VAC through relay coil (Rdhw). Relay contact (Rdhw-1) closes to supply 120 VAC to circulator (Pdhw). Heated water from the buffer tank passes through the brazed-plate stainless steel heat exchanger (HX1) and transfers heat to the domestic water. This water passes into the dip tube of the electric water heater. Any additional temperature rise is provided by the upper electric heating element in the water heater.

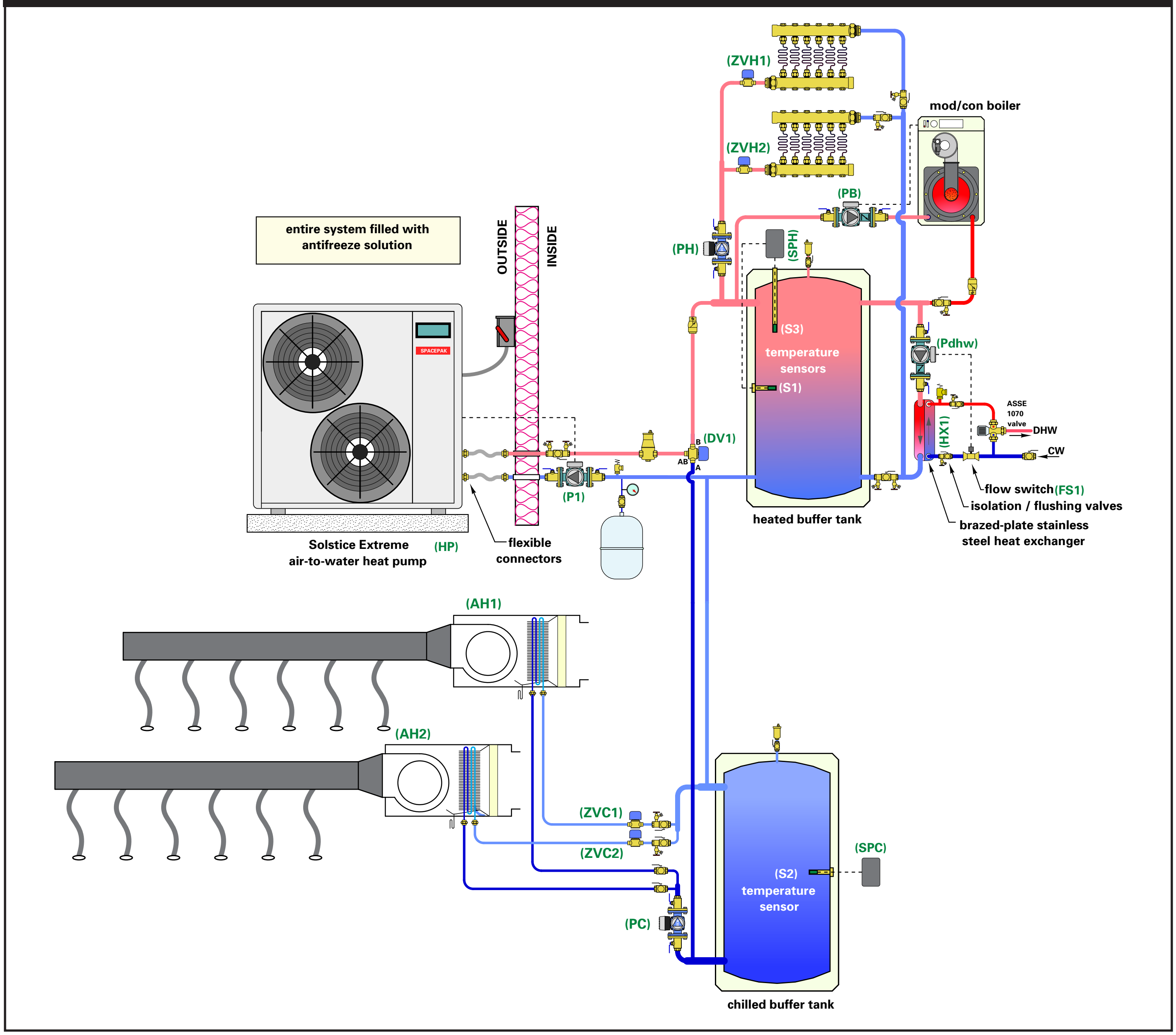
POSSIBLE CONTROLLER SETTINGS:

Temperature at sensor (S1) to begin heating buffer tank = 100ºF
Temperature at sensor (S1) to stop heating buffer tank = 120ºF
Temperature at sensor (S2) for heat pump on (cooling mode) = 60ºF
Temperature at sensor (S2) for heat pump off (cooling mode) = 44ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≤ 41ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≥ 43ºF

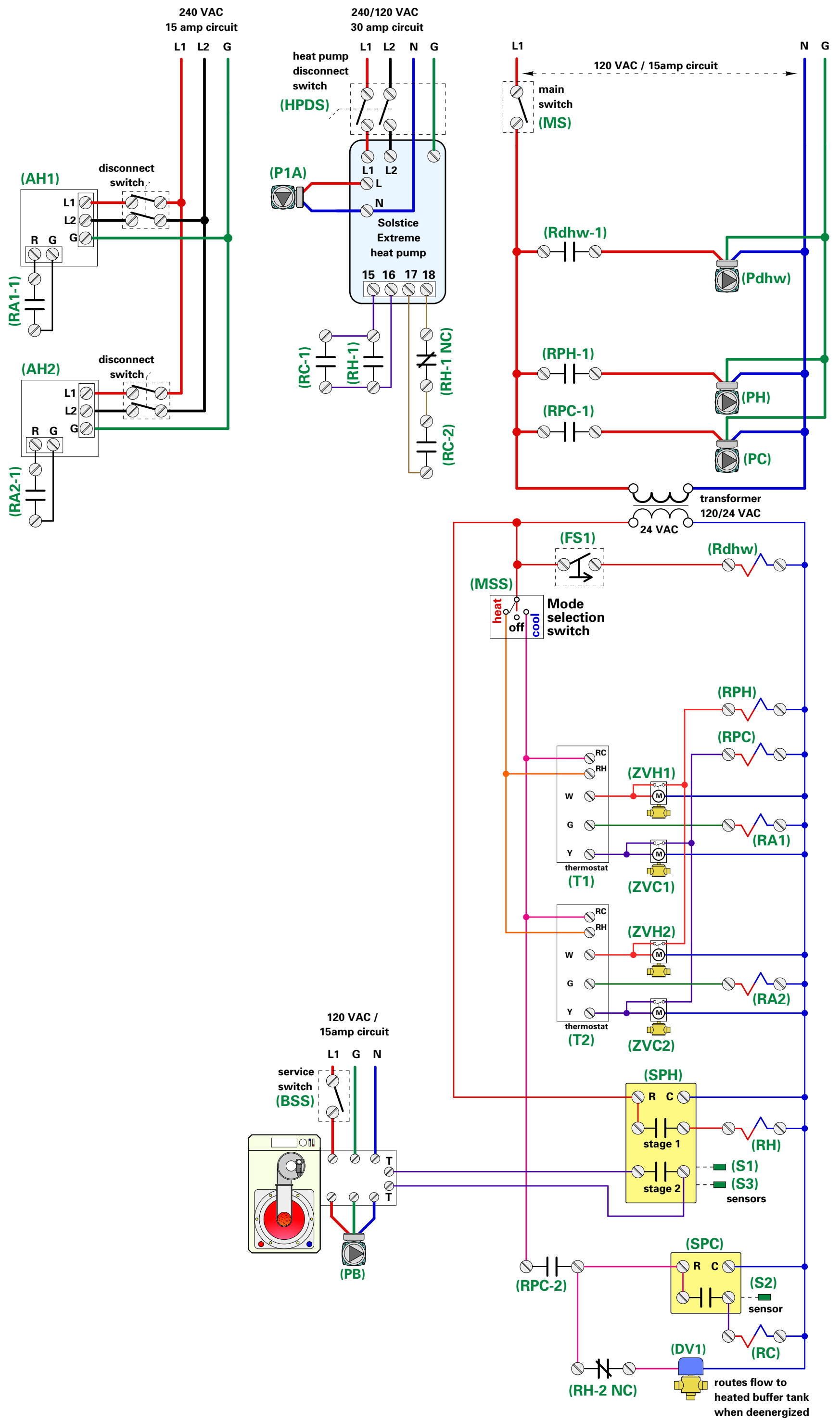
SYSTEM #8:

DESCRIPTION: This system is a variation of system #7. It adds a modulating/condensing boiler to the system to serve as a backup and supplemental heat source for space heating and domestic water heating. When enabled, the boiler adds heat to the upper portion of the buffer tank. The thermal mass of the upper portion of the tank protects the boiler against short cycling due to partial heat demand. The boiler is only allowed to fire after the control system has called for heat pump operation for a minimum of 5 minutes AND the water temperature in the upper portion of the buffer tank has dropped to or below 110ºF. If an all-electric system is needed, an electric boiler could be used in place of the gas-fired boiler.

PIPING SCHEMATIC:



ELECTRICAL SCHEMATIC:



Description of operation:

Power supply: The Solstice Extreme heat pump and circulator (P1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power to the heat pump. The remainder of the control system is powered by 120 VAC/15 amp circuit. The main switch (MS) must be closed to provide power to the control system. Both air handlers are powered by a dedicated 240 VAC/15 amp circuit. The disconnect switch for each air handler must be closed for that air handler to operate. The mod/con boiler is powered by a dedicated 120 VAC/15 amp circuit.

Heat pump operation (heating mode): Whenever the main switch (MS) is closed, 24 VAC is passes to the (2-stage) heating setpoint controller (SPH), which monitors the temperature of the buffer tank at sensor (S1). When the temperature at sensor (S1) drops below 110ºF, the stage 1 contacts in (SPH) close. This completes a circuit between terminals 15 and 16 in the Solstice Extreme heat pump, enabling it to operate in heating mode. After a short time delay, circulator (P1) is supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal flow switch, and when adequate flow is proven, starts the heat pump in heating mode. The system continues in this mode until the temperature at sensor (S1) reaches 120ºF, at which point the contacts in the (SPH) open its stage 1 contacts, turning off the heat pump and circulator (P1). The motorized diverter valve is off during heating mode. Flow passes from its AB port to its B port.

Boiler Operation: The stage 2 contacts of the (SPH) controller close if:

1. The stage 1 contact of the (SPH) has been closed for at least 5 minutes.
2. The temperature at sensor (S3) drops to 110ºF or less.

If the stage 2 contacts close, a circuit is completed across the (T T) terminals (or other boiler operation enabling terminals) of the mod/con boiler. This enables the boiler to fire and turn on circulator (PB). The boiler and circulator continue to operate until the temperature at sensor (S3) reaches 125ºF, at which point the boiler and circulator (PB) turn off. The combined action of the heat pump and mod/con boiler ensure the heated buffer tank remains at a temperature that can fully heat domestic water via heat exchanger (HX1), whenever there's a draw for domestic hot water. The thermal mass of the upper portion of the buffer tank also stabilizes boiler operation against short cycling.

Heat pump operation (cooling mode): The mode selection switch must be set to cooling. The mode selection switch on the thermostats (T1, T2) must also be set for cooling. Whenever either thermostat (T1, T2) calls for cooling, 24 VAC is passed from the Y terminal of the thermostat to the associated zone valve (ZVC1 or ZVC2), causing the valve to open. When the valve is fully open, its internal end switch closes. 24 VAC is passed through the end switch to energize relay (RPC). The normally open contact (RPC-2) closes, passing 24 VAC to the cooling setpoint controller (SPC), which measures the temperature in the chilled buffer tank at sensor (S2). If the temperature at (S2) exceeds 60ºF, the normally open contact in (SPC) closes, passing 24 VAC to relay coil (RC). The diverter valve (DV1) is also powered on by 24 VAC, routing flow from the AB port of the valve to the A port of the valve. This allows flow between the heat pump and chilled buffer tank. Normally open contact (RC-1) also closes between terminals 15 and 16 on the heat pump, enabling it to operate. Normally open contact (RC-2) closes across terminals 17 and 18 on the heat pump, enabling cooling mode. After a short time delay, circulator (P1) will be supplied with 120 VAC from the heat pump. This establishes flow of the system's antifreeze solution through the heat pump. The heat pump verifies adequate flow using its internal flow switch, and when adequate flow is proven, starts the heat pump compressor. The system continues in this mode until the temperature at sensor (S2) drop to 45ºF, at which point the contacts in the (SPC) open, turning off relay coil (RC), which turns off the heat pump circulator (P1) and diverter valve (DV1). The heat pump also turns off if it reaches its lower cooling limit temperature of 41ºF.

Cooling Override: If the mode selection switch is set for cooling, and there is a call from heating setpoint controller (SPH) to heat the heated buffer tank, relay contact (RH-1 NC) opens, putting the heat pump in heating mode. Relay contact (RH-2 NC) opens to interrupt 24 VAC to motorized diverter valve (DV1), enabling flow from the heat pump to the heated buffer tank. Relay contact (RH-1) closes, enabling the heat pump to operate in heating mode. Cooling operation is

temporarily interrupted until the heated buffer tank reaches 120°F at sensor (S1) (which will be a short time during cooling season). This ensures heat within the heated buffer tank for use in domestic water heating.

Space heating distribution: The mode selection switch (MSS) must be set for heating. The mode selection switch on thermostats (T1, T2) must also be set for heating. When a call for heat comes from either of the two zone thermostats (T1, T2), 24 VAC is passed from the RH terminal of the thermostat to the W terminal. This energizes the heating zone valves (ZVH1 or ZVH2), causing them to open. When the zone valve is fully open, its internal end switch closes. 24 VAC is passed through the end switch to energize really coil (RPH). Normally open contact (RPH-1) closes to pass 120 VAC to heating distribution circulator (PH). Circulator (PH) is a variable-speed pressure-regulated circulator set to maintain a fixed differential pressure on the heating distribution system when either zone valve, or both zone valves, open. Heated fluid from the buffer tank is circulated through the manifold station(s) for the radiant panels. 24 VAC will also be passed from the G terminal of the thermostats to relay coils (RA1 or RA2). This will close contacts (RA1-1 or RA2-1), which would turn on the air handlers (AH1 or AH2). However, the air handlers can be prevented from operating in heating mode by turning off their disconnect switch.

Space cooling distribution: The mode selection switch (MSS) must be set for cooling. The mode selection switch on the two thermostats (T1, T2) must also be set for cooling. The disconnect switches on both air handlers must be set to on. When a call for cooling comes from either of the two zone thermostats (T1, T2), 24 VAC is passed from the RC terminal of the thermostat to the Y terminal. This energizes the associated zone valve (ZVC1 or ZVC2), causing them to open. When the zone valve is fully ope, its internal end switch closes. 24 VAC is passed through the end switch to energize relay coil (RPC). Normally open contact (RPC-1) closes to pass 120 VAC to cooling distribution circulator (PC). Circulator (PC) is a variable-speed pressure-regulated circulator set to maintain a fixed differential pressure on the cooling distribution system when either zone valve, or both zone valves, open. Circulator (PC) provides flow through the cooling distribution system. 24 VAC will also be passed from the G terminal of the thermostats to relay coils (RA1 or RA2). This will close contacts (RA1-1 or RA2-1), which turns on the blowers in the air handlers (AH1 or AH2).

Domestic water heating: Whenever there is draw of domestic hot water, cold domestic water passes through the flow switch (FS1). This switch closes its contact whenever flow reaches 0.7 gallons per minute or higher. This passes 24 VAC through relay coil (Rdhw). Relay contact (Rdhw-1) closes to supply 120 VAC to circulator (Pdhw). Heated water from the buffer tank passes through the brazed-plate stainless steel heat exchanger (HX1) and transfers heat to the domestic water. The heat exchanger (HX1) has been sized to fully heat domestic water from 50 to 110°F at flow rates up to 4 gpm in a single pass.

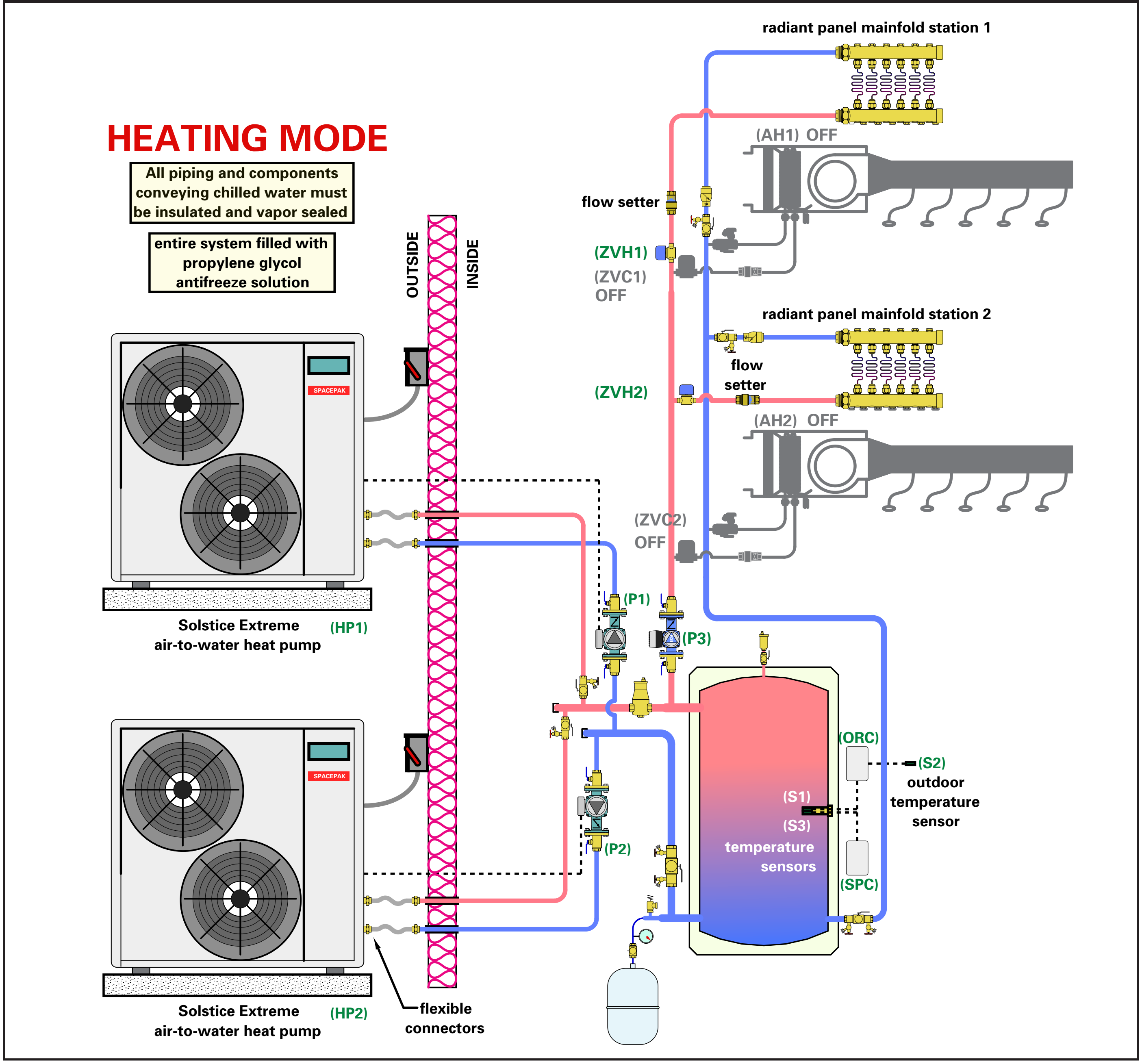
POSSIBLE CONTROLLER SETTINGS:

Temperature at sensor (S1) for heat pump to begin heating buffer tank ≤ 110°F
Temperature at sensor (S1) for heat pump to stop heating buffer tank ≥ 120°F
Temperature at sensor (S3) for boiler to begin heating buffer tank ≤ 110°F
Temperature at sensor (S3) for boiler to stop heating buffer tank ≥ 125°F
ASSE 1070 tempering valve setting = 110°F
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130°F
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 127°F
Temperature at sensor (S2) for heat pump on (cooling mode) = 60°F
Temperature at sensor (S2) for heat pump off (cooling mode) = 45°F
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≤ 41°F
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≥ 43°F

SYSTEM #9:

Description: This system provides two independent zones of heating and cooling. Both zones must operate in the same mode at the same time. Space heating is provided by radiant panels. Cooling is provided by two SpacePak WCSP-J air handlers. Flow to all heating and cooling zones is provided by a single variable-speed pressure-regulated circulator that automatically changes speed to maintain constant differential pressure regardless of which zone(s) are operating.

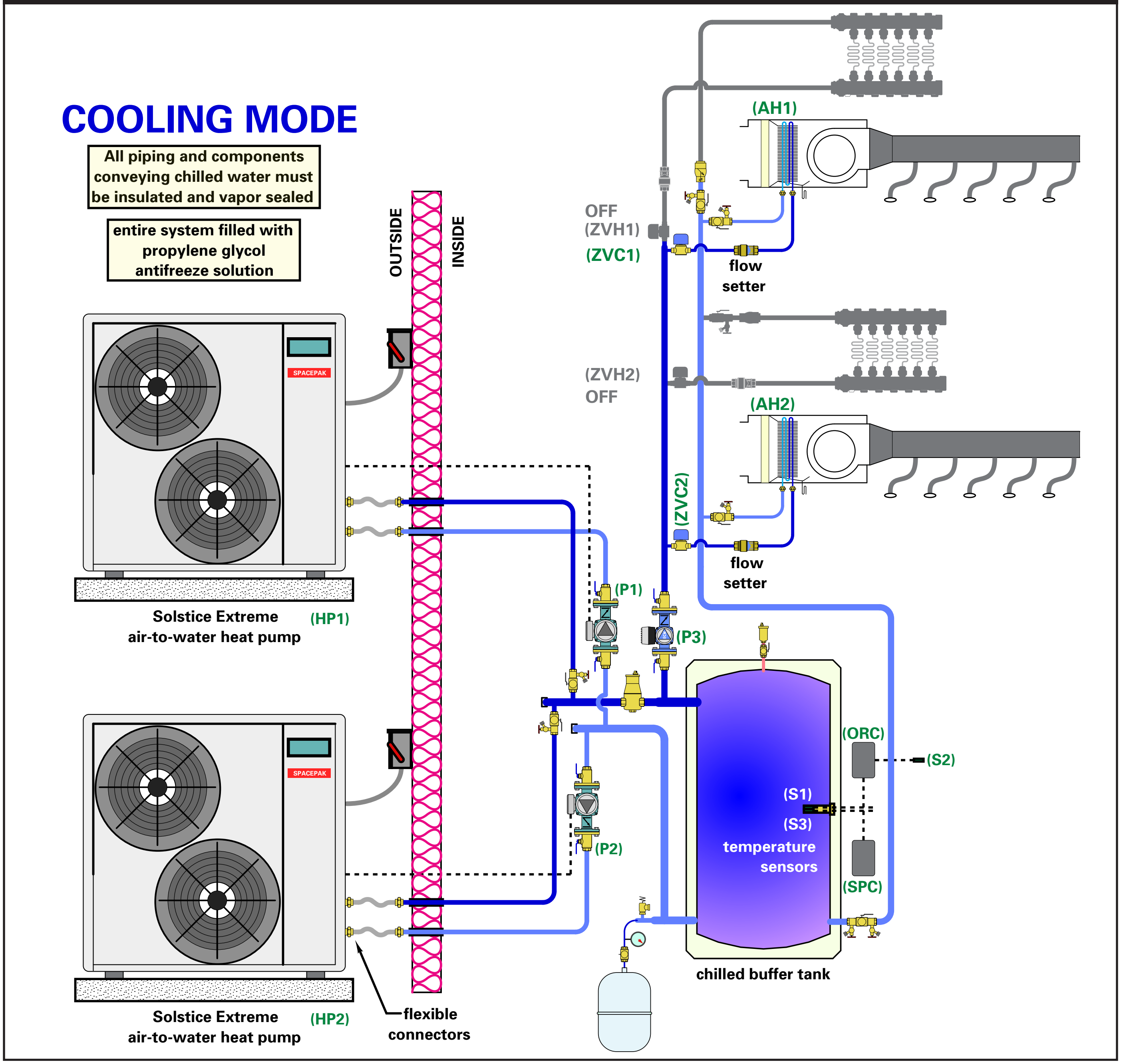
PIPING SCHEMATIC (HEATING MODE):



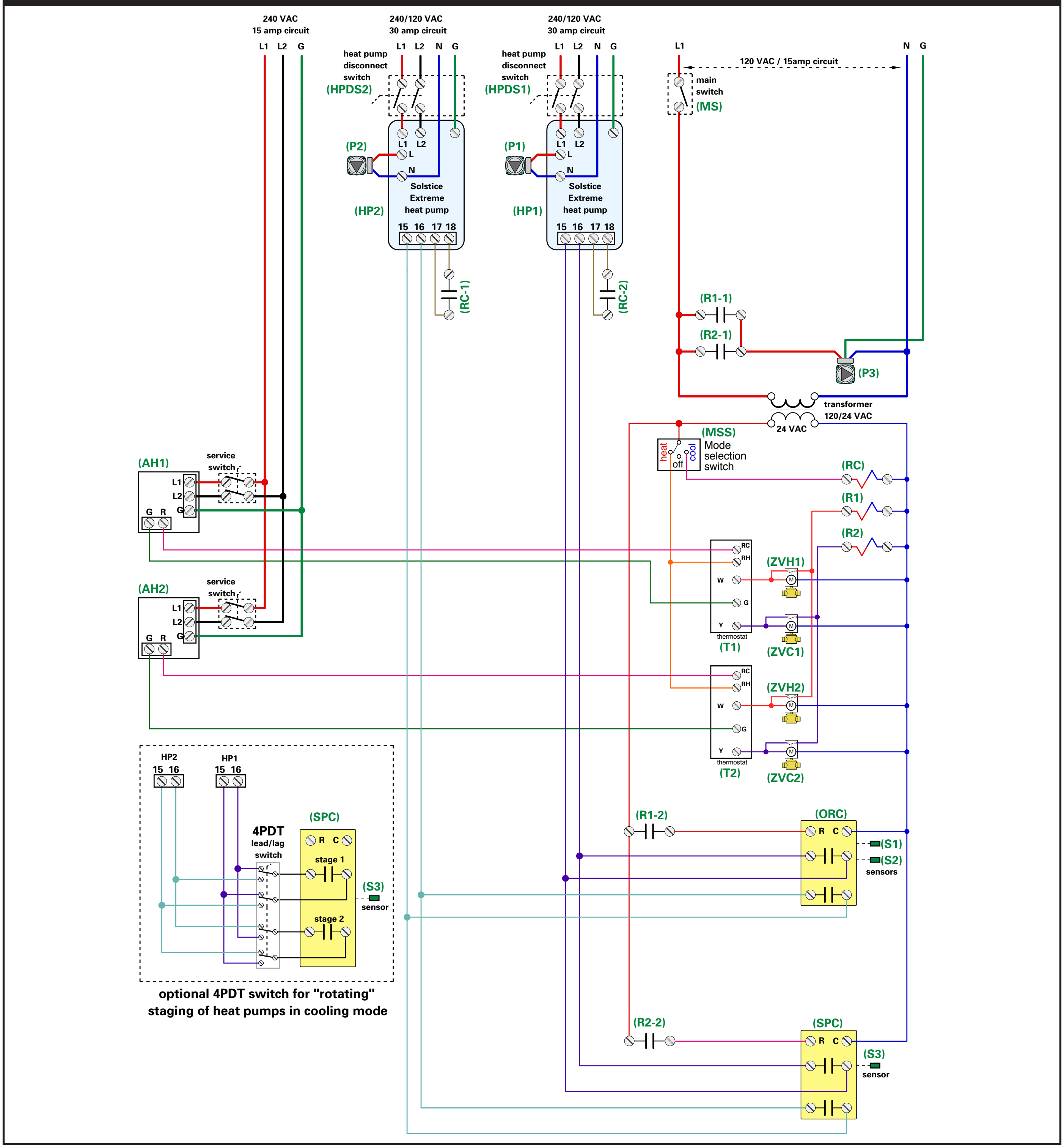
This system also uses *two* Solstice Extreme heat pumps that are controlled in stages, depending on the heating and cooling loads. Two heat pumps also provide automatic partial heating and cooling capacity if one heat pump is out of service.

During heating mode operation, the fluid temperature in the buffer tank is regulated by an outdoor reset controller. The maximum target water temperature at the mid-height sensor (S1) in the buffer tank is 110ºF, corresponding to an outdoor

PIPING SCHEMATIC (COOLING MODE):



ELECTRICAL SCHEMATIC:



temperature of 0ºF. The minimum target water temperature at sensor (S1) is 80ºF corresponding to an outdoor temperature of 52.5ºF or higher. Outdoor reset control of the buffer tank temperature allows the system to meet the heating load of the building, while maintaining the lowest possible water temperature required of the heat pump, which maximizes its coefficient of performance.

During cooling mode, the temperature of the fluid in the buffer tank is maintained between an upper and lower limit by a 2-stage temperature setpoint controller.

The buffer tank is piped in a 3-pipe configuration, and its piping is optimized for heating mode operation.

All piping carrying chilled fluid must be insulated and vapor sealed.

During heating mode, the staging order of the heat pumps is assumed to be automatically rotated by the 2-stage outdoor reset controller. This allows each heat pump to accumulate approximately the same number of hours over each heating season. The electrical schematic also shows an optional 4PDT switch and associated wiring that can be used to periodically change the operating order of the two heat pumps. This option can be used in either heating or cooling mode, if the 2-stage controller for that mode does not have an automatic rotation option. One 4PDT switch would be required for each mode.

The entire system is filled with a 30% solution of inhibited propylene glycol antifreeze.

The basic piping and control concepts used in this system can be extended to create systems with more zones or additional heat pumps.

Description of operation:

Power supply: Each Solstice Extreme heat pump (HP1, HP2), along with its associated circulator (P1, P2), is powered by dedicated 240/120 VAC 30 amp circuits. The heat pump disconnect switches (HPDS1, HPDS2) must be closed to provide power to the heat pumps. The remainder of the control system is powered by a 120 VAC/15 amp circuit. The main switch (MS) must be closed to provide power to the control system. Both fan-coils are powered by a dedicated 120 VAC/15 amp circuit. The service switch for each air handler must be closed for that air handler to operate.

Heating mode: The mode selection switch (MSS) must be set for heating, and each thermostat must be set to heating mode. This passes 24 VAC to the RH terminal in each thermostat. Whenever either thermostat demands heat, 24 VAC is passed to the associated zone valve (ZVH1 or ZVH2). When the zone valve reaches its fully open position, its internal end switch closes, passing 24 VAC to relay coil (R1). Relay contact (R1-1) closes to pass 120 VAC to circulator (P3). Circulator (P3) is a variable-speed pressure-regulated circulator set to operate in constant differential pressure mode. It will automatically adjust its speed, depending on the number of active zone circuits. The flow rate through each manifold station is regulated by the flow setter. Relay contact (R1-2) closes to pass 24 VAC to a 2-stage outdoor reset controller (ODR). The (ODR) measures outdoor temperature at sensor (S2), and uses this temperature, along with it settings, to calculate the target supply water temperature for the buffer tank. It then measures the temperature of the buffer tank at sensor (S1). If the temperature at (S1) is more than 3ºF below the target temperature, the (ODR) closes its stage 1 relay contact. This completes a circuit between terminals 15 and 16 in the Solstice extreme heat pump (HP1), enabling it in heating mode. After a short time delay, heat pump (HP1) turns on circulator (P1) and verifies adequate flow through the heat pump. After a short time delay, the heat pump turns on its compressor. If, after a short time delay, the 2-stage (ORC) is not detecting an adequate increase in the temperature of sensor (S1), it closes its stage 2 contact. This completes a circuit between terminals 15 and 16 in the Solstice extreme heat pump (HP2), enabling it in heating mode. After a short time delay, the heat pump (HP2) turns on circulator (P2) and verifies adequate flow through the heat pump. After a short time delay, heat pump (HP2) turns on its compressor. Both heat pumps continue to operate in this mode until the temperature at sensor (S1) is 3ºF above the target temperature calculated by the (ODR), or neither thermostat calls for heat, or either heat pump reaches its internal high-limit setting. *Note: The air handlers <u>will</u> operate in heating mode, regardless of the fan switch setting on the thermostats. If either air handler should remain off when the system is in heating mode, turn off its service switch.*

Note: The 2-stage outdoor reset controllers (ORC) are assumed to have a heat source "rotation" mode to periodically alter the starting order of the heat pumps to ensure approximately equal run time. This feature should be enabled on the (ORC) controller.

Cooling mode: The mode selection switch (MSS) must be set for cooling, and each thermostat must be set for cooling. This passes 24 VAC to relay coil (RC). Normally open contacts (RC-1) and (RC-2) close across terminals 17 and 18 in each heat pump (HP1, HP2), enabling them to operate in cooling mode when they are turned on. Whenever either thermostat calls for cooling, 24 VAC is passed to the associated zone valve (ZVC1 or ZVC2). When the zone valve reaches its fully open position, its internal end switch closes, passing 24 VAC to relay coil (R2). Relay contact (R2-1) closes to pass 120 VAC to circulator (P3). Circulator (P3) is a variable-speed pressure-regulated circulator set to operate in constant differential pressure mode. It will automatically adjust its speed, depending on the number of active zone circuits. The flow rate through each air handler is regulated by the flow setter. Relay contact (R2-2) closes to pass 24 VAC to the 2-stage cooling setpoint controller (SPC). The cooling setpoint controller measures the temperature of the buffer tank at sensor (S3). If this temperature is 60ºF or higher, the (SPC) relay contact closes it stage 1 contact to complete a circuit between terminals 15 and 16 on the Solstice Extreme heat pump (HP1), enabling it to operate in cooling mode. Heat pump (HP1) turns on circulator (P1) and verifies adequate flow through the heat pump. After a short time delay, the heat pump turns on its compressor and operates in chiller mode. If, after a 5 minute time delay, the temperature at sensor (S3) has not dropped to 55ºF or lower, the SPC controller closes its second stage contacts. This completes a circuit between terminals 15 and 16 in heat pump (HP2), turning it and its associated circulator (P2) on in cooling mode. Both heat pumps and their associated circulators continue to operate until the temperature at sensor (S3) drops to 44ºF, at which point both heat pumps and their circulators turn off. Both heat pumps will also turn off if neither zone is calling for cooling, or if either heat pump reaches its internal low-limit setting. The blowers in the air handlers can be manually turned on at the thermostats when the mode selection switch (MSS) is set to cooling. The blowers will operate automatically whenever either cooling zone is active.

Note that if the 2-stage setpoint controller does not provide a "rotation" feature for staging priority, a manually operated 4PDT switch can be used to periodical alter the starting order of the heat pumps in cooling mode.

POSSIBLE CONTROLLER SETTINGS:

Outdoor design temperature = 10ºF
Outdoor temperature corresponding to no load = 70ºF
Target temperature at sensor (S1) at design conditions = 100ºF
Target temperature at sensor (S1) at no load = 70ºF
Minimum temperature to be maintained at sensor (S1) = 80ºF
(ORC) contacts open when sensor (S1) = [target temperature + 3ºF]
(ORC) contacts close when sensor (S1) = [target temperature - 3ºF]
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≥ 130ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≤ 125ºF
Temperature at sensor (S3) for heat pump 1 ON (cooling mode) = 60ºF
Temperature at sensor (S3) for heat pump 1 OFF (cooling mode) = 44ºF
Temperature at sensor (S3) for heat pump 2 ON (cooling mode) = 55ºF (after 5 minute delay)
Temperature at sensor (S3) for heat pump 1 OFF (cooling mode) = 44ºF
Solstice Heat Pump internal controller turns OFF heat pump if leaving fluid temperature ≤ 41ºF
Solstice Heat Pump internal controller turns ON heat pump if leaving fluid temperature ≥ 43ºF

SYSTEM #10:

DESCRIPTION: This system provides heating and cooling using multiple SpacePak WCSP-J air handlers. Each air handler is a separate zone. All zones must operate in the same mode (e.g., heating or cooling) at the same time. The system is controlled by a SpacePak SSIC controller, which manages the heat pump, boiler, buffer tank and up to five independent air handlers.

The system uses a modulating/condensing boiler that provides supplemental heat output when necessary.

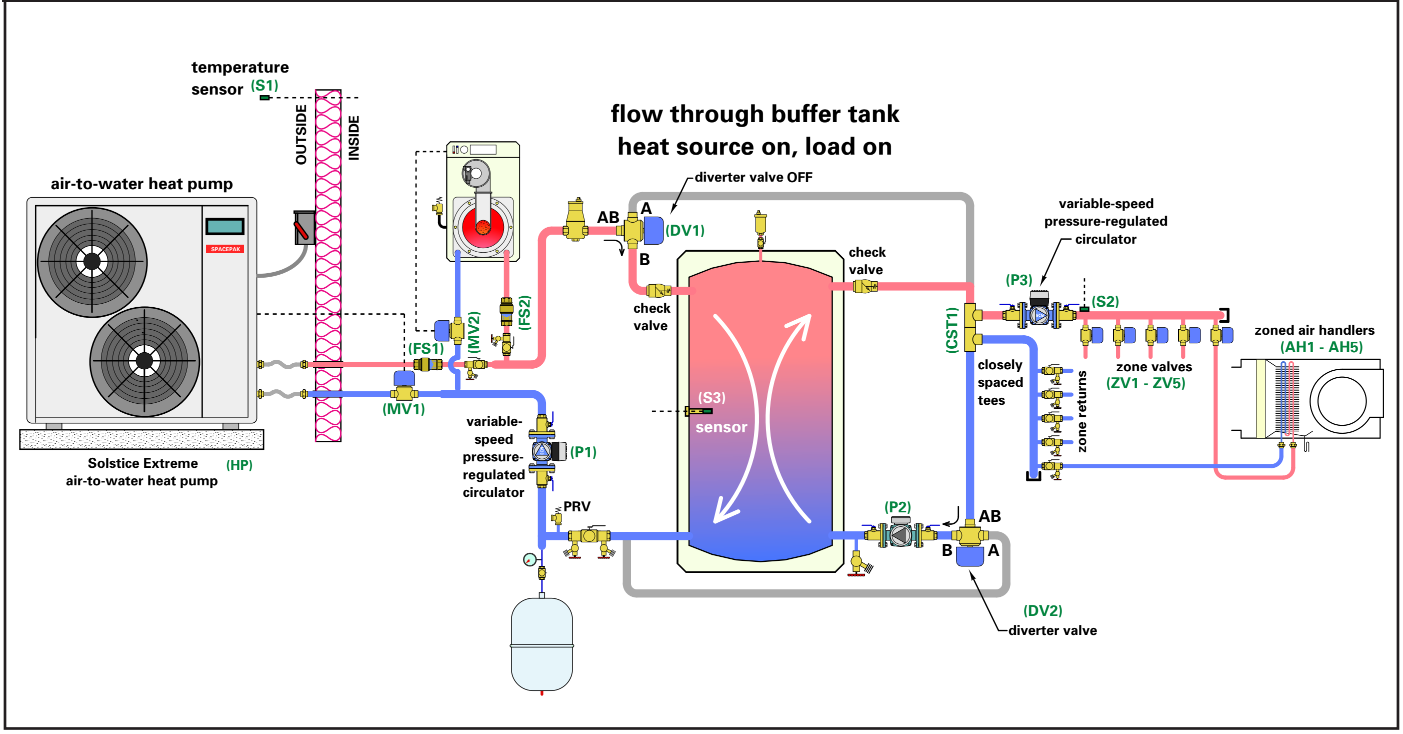
The system includes a buffer tank. That tank is equipped with diverter valves that allow flow from either the Solstice Extreme heat pump or the boiler to pass through the buffer tank in a standard "4-pipe" configuration, or to completely bypass the buffer tank when the load is high. Pass-through or bypass modes are controlled by the SSIC controller.

Description of operation:

Power supply: The Solstice Extreme heat pump and its associated motorized valve (MV1) are powered by a dedicated 240/120 VAC 30 amp circuit. The heat pump disconnect switch (HPDS) must be closed to provide power to the heat pump. The boiler and its associated motorized valve (MV2) are powered by a dedicated 120 VAC/15 amp circuit. The boiler service switch (BSS) must be closed for the boiler and motorized valve to operate. Each air handler is powered by a dedicated 240 VAC/15 amp circuit. The disconnect at each air handler (DS1 - DS5) must be closed for the air handler to operate. The remainder of the control system is powered by 120 VAC/20 amp circuit. The main switch (MS) must be closed to provide power to the control system.

SSIC Controller: When a load calls for heating or cooling, the SSIC controller measures the temperature of the buffer tank at sensor (S3). If the buffer tank is at a suitable temperature, neither the heat pump nor boiler will be turned on. The multi-zone relay center (MZRC) turns on the distribution circulator (P3) and circulator (P2). Heated fluid or chilled fluid (depending on system operating mode) is routed from the buffer tank to the closely spaced tees (CST1) and handed off to the distribution circulator (P3). Circulator (P2) is turned off

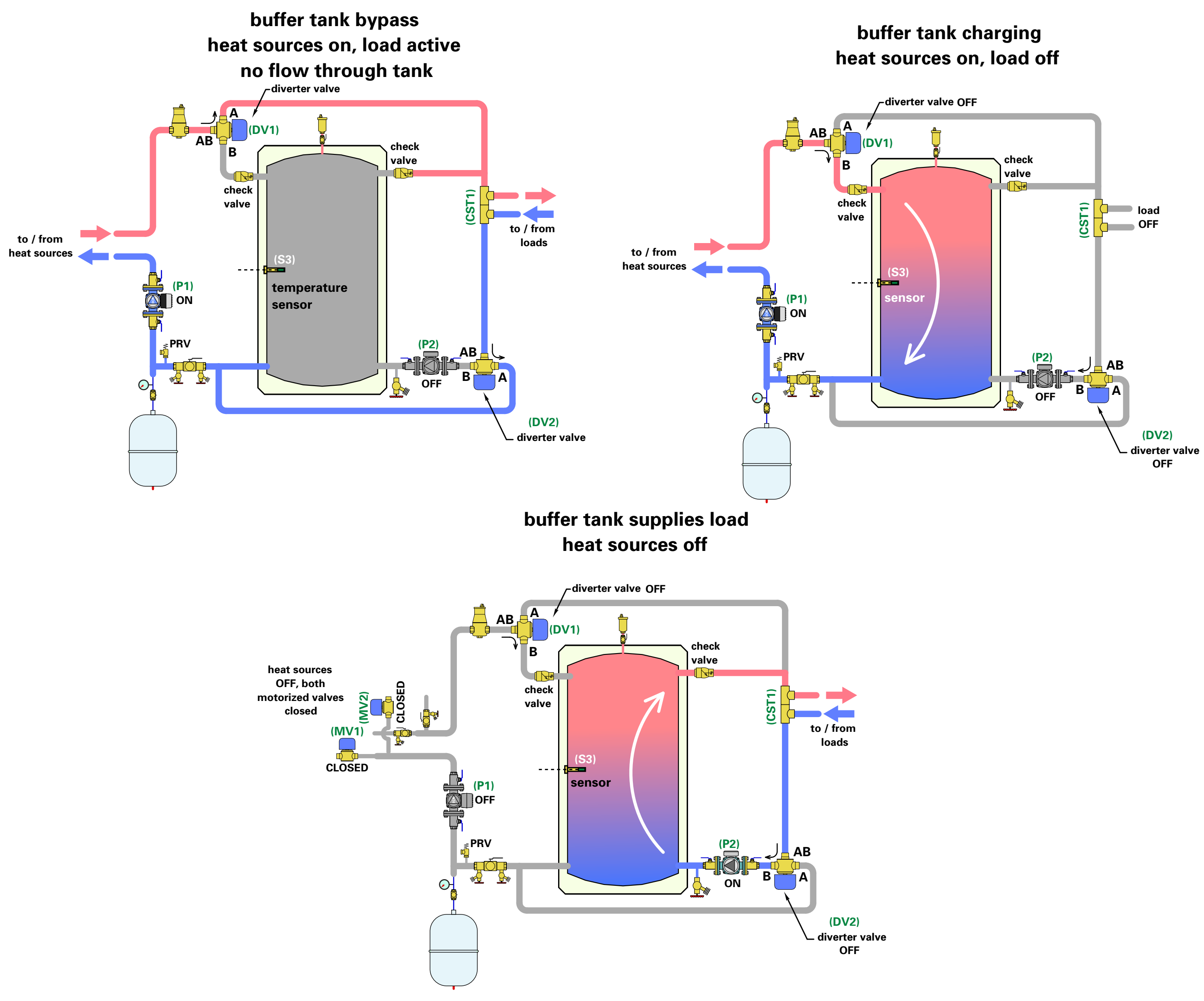
PIPING SCHEMATIC (HEATING MODE):



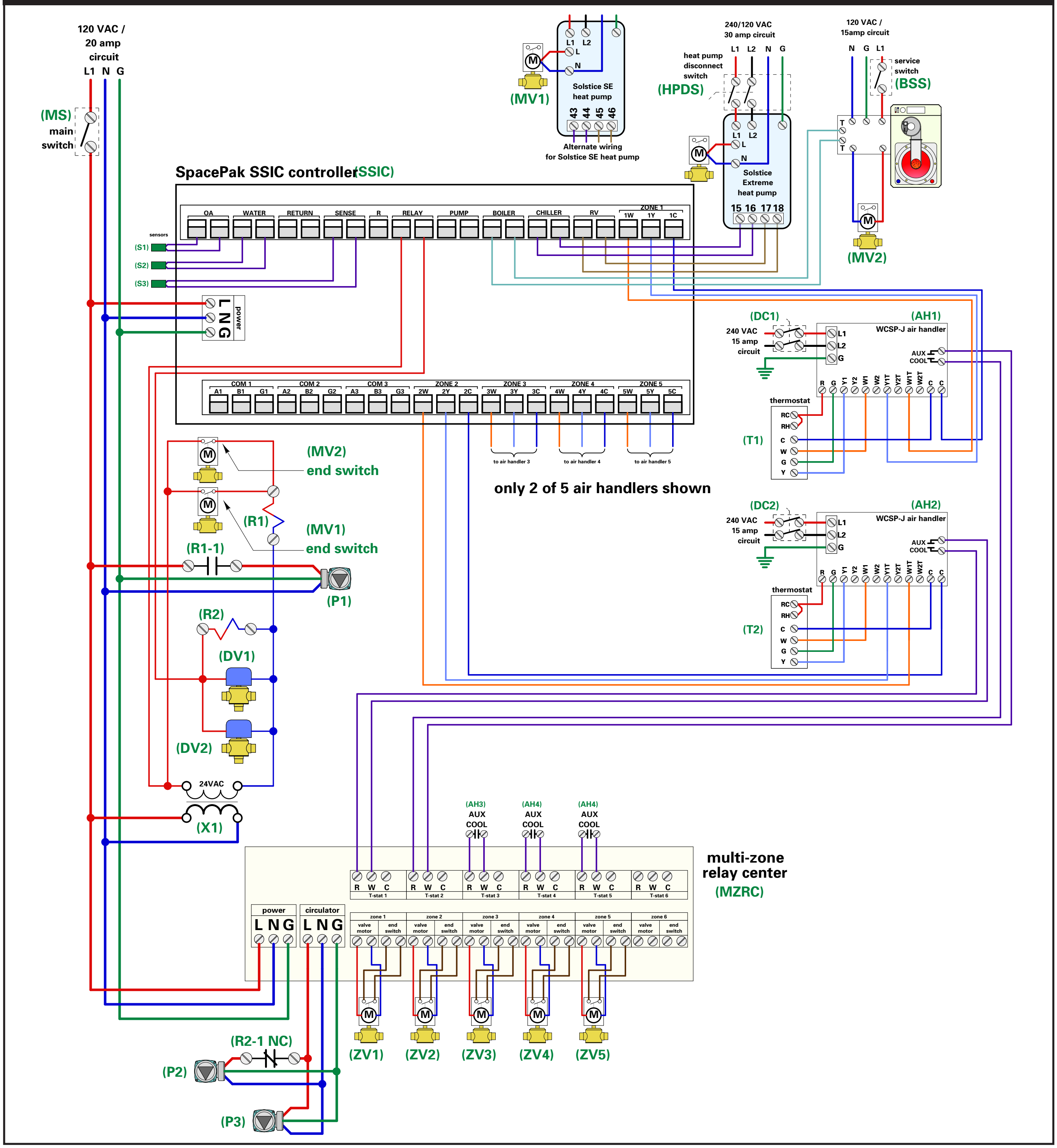
whenever the diverter valves are in tank bypass mode. When 24 VAC passes to the diverter valves to put them in tank bypass mode, 24 VAC also powers-on the coil of relay (R2). Relay contact (R2-1 NC) opens to turn off circulator (P2). See the latest installation and operation manual for the SpacePak SSIC controller for details on the controller's setting option and operation.

Air Handler Operation: When the disconnect at each air handler is closed, 24 VAC passes to the (RH) and (RC) terminals of the zone thermostat associated with that air handler. The mode selection (heat or cool) of the thermostat for zone 1 (T1) determines the mode status (heating or cooling) for all other zones. When a thermostat calls for heat, 24 VAC is passed from the W1 terminal of that thermostat to the W1

PIPING SCHEMATIC (BUFFER TANK MODES DURING HEATING):



ELECTRICAL SCHEMATIC:



terminal of the air handler. The air handler turns on its blower, and closes the "aux cool" relay contact. _NOTE: The DIP switch setting on the air handler must be set to allow the "aux cool" contact to close in both heating and cooling mode._ The closed "aux cool" contact provides a call for zone operation at the multi-zone relay center (MZRC). The (MZRC) powers on (e.g., opens) the associated zone valve (ZV1 - ZV5). When the zone valve reaches its fully open position, its internal end switch closes. This signals the multi-zone relay center (MZRC) to turn on circulator (P3). Circulator (P3) is a variable-speed pressure-regulated circulator set to operate in constant differential pressure mode. It changes speed automatically as zone valves open and close. Circulator (P2) will also turn on to move water from the buffer tank to the closely spaced tees (CST1) unless the diverter valves (DV1 and DV2) are powered on for flow to bypass the buffer tank, in which case relay coil (R2) is on, and relay contact (R2-1 NC) opens to turn off circulator (P2).

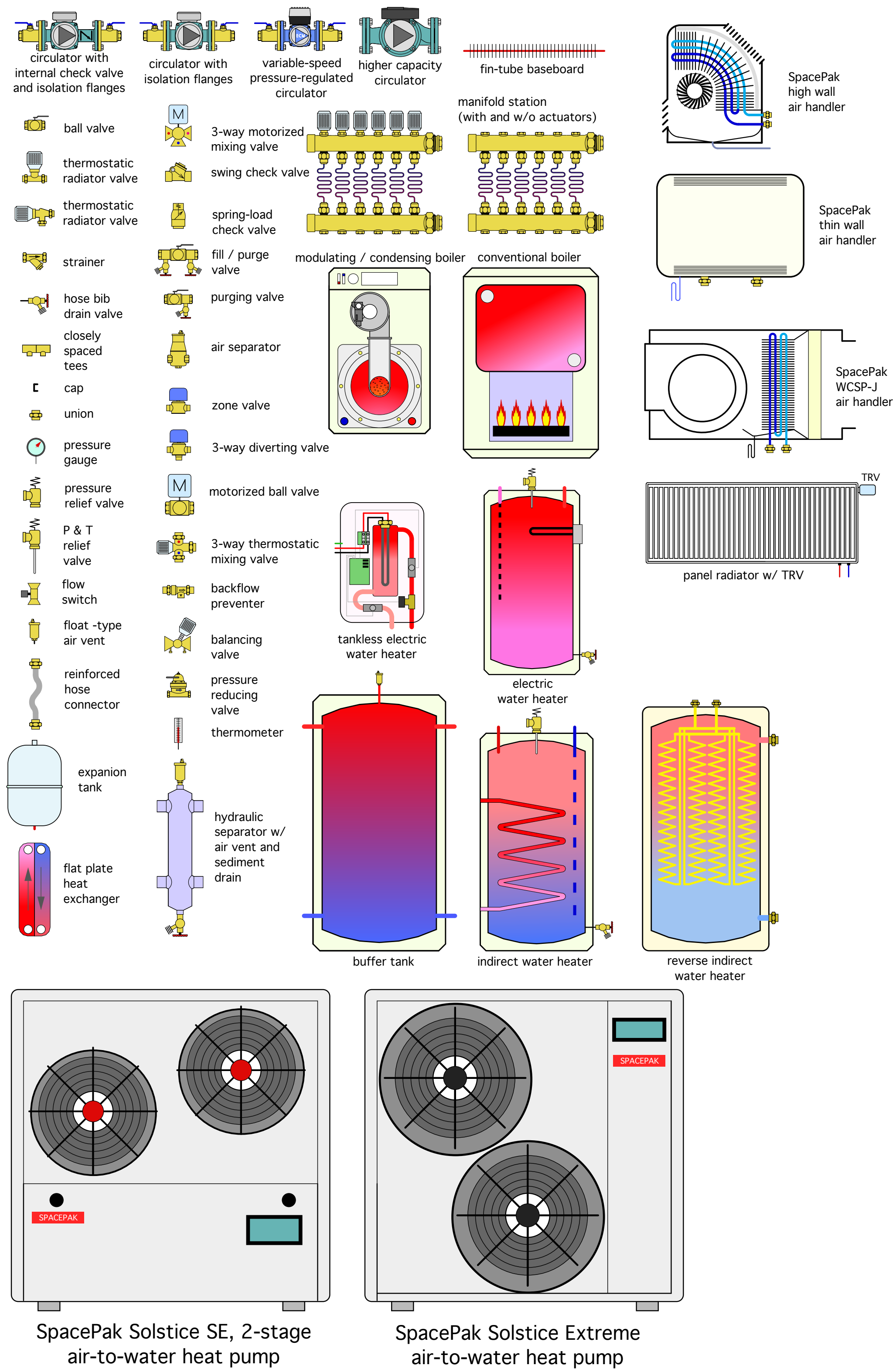
Heat Input: Whenever the zone 1 thermostat (T1) is set for heating mode, the entire system will operate in heating mode. A call for heat from any of the five thermostats will activate the associated air handler and send a heating call to the SSIC controller. The SSIC controller will respond by turning on the heat pump, boiler, or both, based on its settings and the current outdoor temperature and buffer tank temperature.

Heat pump supplied heat: When the Solstice Extreme heat pump (HP) is turned on by the SSIC controller, motorized valve (MV1) opens, allowing flow through the heat pump. The flow regulator (FS1) will maintain the desired (preset) flow rate through the heat pump. Heated fluid passes either into the buffer tank or around the buffer tank, depending on the status of the diverter valves (DV1, DV2). The diverter valves route flow through the buffer tank (e.g., from their AB port to their B port) when unpowered. When powered on by 24 VAC from transformer (X1) and routed through the "RELAY" contact on the SSIC controller, the flow at each diverter valve will be from its AB port to its A port, fully bypassing the buffer tank. The heated fluid is delivered to the closely spaced tees (CST1) connected to the distribution headers. Flow then passes to any active air handler.

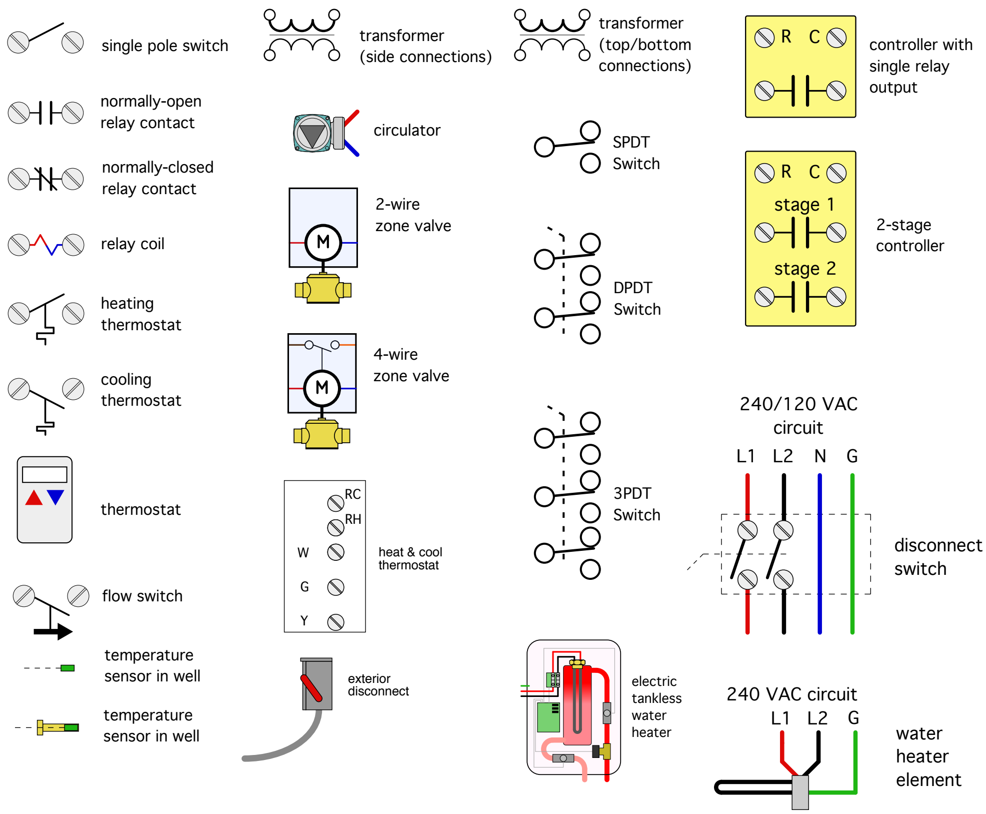
Boiler supplies heat: The SSIC controller will also turn on the boiler when necessary for supplemental heating. When called to operate, the boiler will power open its motorized valve (MV2). The speed of circulator (P1) will increase to maintain the same differential pressure across the heat pump and boiler regardless of which (or both) are operating. The flow regulator (FS2) will maintain the desired (preset) flow rate through the boiler.

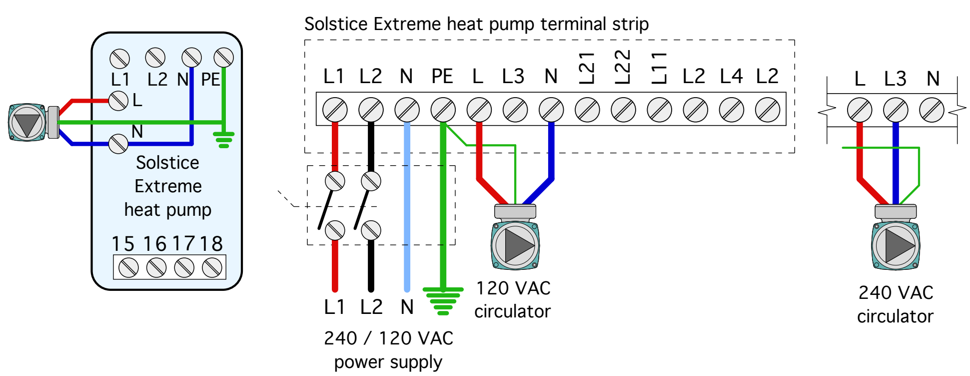
Cooling input: Whenever the zone 1 thermostat (T1) is set for cooling mode, the entire system will operate in cooling mode. A call for cooling from any of the five thermostats activates the associated air handler and sends a heating call to the SSIC controller. The SSIC controller responds based on its settings, the current outdoor temperature, the buffer tank temperature at sensor (S3), and the fluid temperature at sensor (S2). It will turn on the Solstice Extreme heat pump (HP) in cooling mode, creating chilled-fluid input to either the buffer tank or around the buffer tank, depending on the status of the diverter valves (DV1, DV2) which are controlled by the SSIC controller. The heated fluid is delivered to the closely spaced tees connected to the distribution headers (CST1). Chilled fluid then passes through the coil of any active air handler.

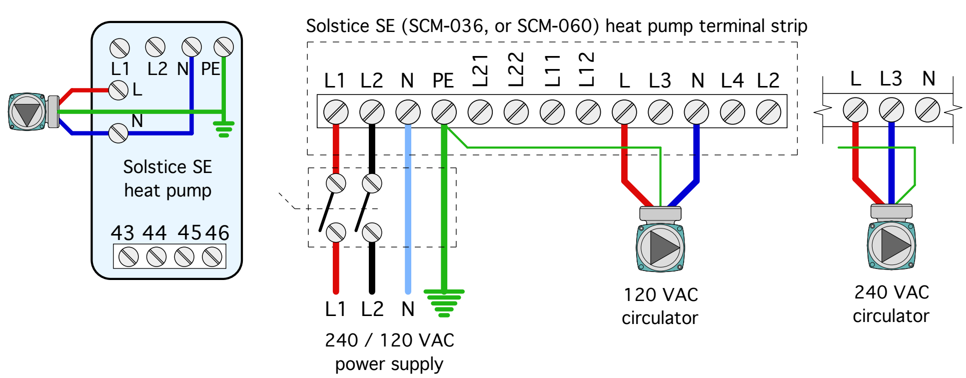
APPENDIX A: Piping Component Symbol Legend



Appendix B: Electrical component symbol legend







APPENDIX C: References for Hydronic System Design

1. **Modern Hydronic Heating, 3rd Edition**, John Siegenthaler, P.E.
Cengage Publishing, 2012 , ISBN-13:978-91-4283-3515-8

2. **Heating with Renewable Energy**, John Siegenthaler, P.E.
Cengage Publishing, 2017, ISBN-13: 978-1-2850-7560-0

SpacePak is a manufacturer of premium heating and cooling products and takes great pride in being a solutions provider. Our water based products provide energy efficient solutions to fit all applications.

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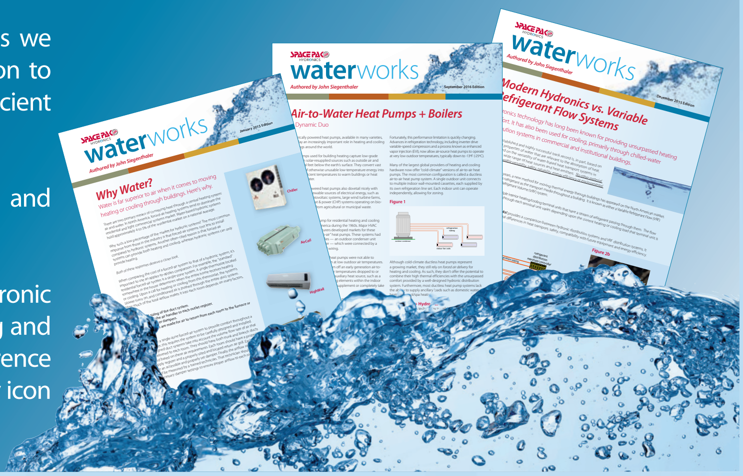

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